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MINUTES

of the Fourth

EXPLOSIVES SAFETY SEMIN

on

HIGH-ENERGY SOLID PROPELL

Held at the

Langley Research Center, Langley,

on

7, 8, 9 August 1962

Armed Services Explosives Safety Boa
Washington 25, D. C.

ARMED SERVICES EXPLOSIVES SAFETY BOARD
Washington

8 January 1963

ERRATA SHEET #2

1. Publication: Minutes of the Fourth Explosives Safety Seminar on High-Energy Solid Propellants held at the Langley Research Center, Langley, Virginia on 7, 8, 9 August 1962, Confidential

2. Make the following corrections:

Pages 498 thru 505, change from Unclassified to Confidential.

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PREFACE

Most of the discussion at the Seminar required no security classification. Certain discussions were classified "Confidential." Each page of these minutes has been stamped to indicate whether or not it contains "Confidential" information or is "Unclassified."

Participants were encouraged to present their own viewpoints. In some cases speakers described practices which differed from those in common use in the explosives industry. The inclusion of such comments in these minutes does not imply that they represent the viewpoint of the Armed Services Explosives Safety Board.

Further exchange of information on how to prevent explosive accidents is encouraged. It is suggested that any questions on portions of discussions be directed to the appropriate speakers, or their sponsoring agencies, rather than to the Armed Services Explosives Safety Board. This will expedite answers and will promote direct exchange of information between principals, which can be so effective in promoting safety.

Please advise the Armed Services Explosives Safety Board of any corrections to be made in these minutes, and errata sheets will be prepared.

The contribution to the cause of promoting explosives safety, by those who devoted valuable time and effort to this Seminar, is very much appreciated.

LELAND S. McCANTS
Colonel, USAF
Chairman, Armed Services
Explosives Safety Board

TABLE OF CONTENTS

SPEAKER INDEX

ORGANIZATIONAL SOURCE INDEX

Minutes of the

Fourth Annual

EXPLOSIVES SAFETY SEMINAR ON HIGH ENERGY SOLID PROPELLANTS

Langley Research Center
Hampton, Virginia

7-9 August 1962

Sponsor

Armed Services Explosives Safety Board

Host

National Aeronautics & Space Administration

Col. A. W. Hamilton, USA, Chairman, ASESB: Gentlemen. At previous meetings as you know, our hosts have been the Army, the Navy and the Air Force. It seems that the Space Agency has an interest in chemical propulsion too so they wanted to become a part of this program of what we started out calling seminars. I think they're really symposiums now. It was only proper that they should become a part of this effort. We're very fortunate in having with us this morning the Director of the Langley Research Center, Mr. Floyd Thompson. He got a degree in Aeronautical Engineering back in 1926 when there weren't so many aeronautical engineers, came right to the Langley Research Center, has been in various positions of increasing responsibility thru the years; about ten years ago he was made Assistant Director and a couple of years ago, was made the Director of the Langley Research Center. Mr. Thompson.

Mr. Floyd Thompson, Director, Langley Research Center: Thank you Col. Hamilton. Gentlemen, we are very happy to be able to play host to an assembly of this type where you've come to pool know-how and knowledge. I didn't realize that the group was quite as large as this, I understand you've grown considerably in the last several years. NASA's interest in this has grown and I think one of the things that bear consideration is how you deal with large rockets. This is an area in which NASA is considerably interested currently. I always get a little shocked considering rockets as explosives, however, we hope the solid fuel rockets are not explosive. We like to think of them as sources of energy that burn in an orderly manner. Of course we're against explosions too, but we are for well regulated and orderly burning in solid fuel rockets, in other words, this is what we want to get. If we were against explosions, this wouldn't make a rocket I suppose, but we are really interested in rockets, solid fuel rockets and currently NASA is giving pretty serious consideration to rather large ones, I think the 240" diameter is the size that is the most compatible with the requirement for manned space flight where you use the solid fuel rocket as the first stage. Many basic requirements as to how fast you can accelerate a man and how fast you can put him through paces where he might want to abort and that sort of thing, it has worked out that you have to get up to some size in that class before you get the right characteristics that are commensurate with manned flights. A rocket that size would be to say the least, spectacular, it would be very costly, it would set the program back very badly. That's one of the things it seems to me that would bear a lot of consideration. In our own experience in NASA, we've been flying manned rocket ships for 15-16 years. The ones I refer to are the liquid rockets, the X-1 airplane that was launched from a mother aircraft, more recently we've gotten to the point of launching men from the ground and now we're getting to the point where we're thinking about the possibility of launching men from the ground with solid rockets. I didn't intend to make a speech. We've tried to arrange the place for your convenience, I think we're going to be able to take care of your transportation, at least we're planning to. We're planning to give you a tour of our

facilities. You will be told more about that tomorrow and with that I wish you success for your meeting and I hope we're able to make things reasonably comfortable and satisfactory for you while you're here. Thank you.

Col. Hamilton: Our next speaker is a gentleman who is known to all of you who have been in the propellant business for any length of time. He's been in it ever since back in the days when we called it smokeless powder. He was a former manager of the Smokeless Powder Division of Hercules Powder Co., later became a Deputy Assistant Secretary of the Army. He has done many many other things, I don't remember them all, you'll have to look him up in Whos Who or American Men of Science to get the whole history, Mr. Henry Marsh.

Mr. Henry Marsh: It's a very real pleasure to be in this spot of opening this the fourth of our safety seminars. This completes a trip around the circle, because first we had the Navy as a host down at Indian Head and it was a nice hot period of time, the air conditioning had been put in but it wasn't working very well; the next year we were down with the Army as host at Redstone in much more satisfactory meeting spot; last year the Air Force hosted our meeting out in the edge of the desert in a room that was certainly not as conveniently arranged and if this size crowd had shown up for that meeting, some of them would have had to sit outside or in a remote control layout and the furtherest of our guests were much further away from the head table and I'm not sure how much of it they heard. Here we are today in a nicely air-conditioned place and our sincere thanks to NASA for providing this and completing the circle around of those that are vitally interested in this particular subject. Our competition with our enemy has compelled us to find new and different things to improve and increase the thrust that we can get from these various solid propellant combinations and this has introduced a whole crop of new problems and everyone of us here in the room are interested in how to use these new things and how to use them with safety. And there are some honeys of problems in this job. When we first got into the matter of solid propellant rockets, there were only a few people who even gave serious consideration to that subject; today this has extended to many many more organizations and it is with a faith of clean interchange of information between this group that we have these seminars. If in some fashion we can exchange information regarding the problems that we individually have run into and in this fashion avoid mistakes that destroy the units and equipment that we are needing to use here and far more importantly if we can avoid the loss of a single life, then this seminar is worthwhile. From the tremendous increase in the size of this from the way it was when it started, apparently you all are just as interested in this problem as we are in the Safety Board. One of the outstanding and important things about our way of doing business is that we do operate under a free enterprise system to decide who will build what and this is fine, but we must not let that competition introduce any competition between us other than

to pool our efforts in order to save lives. Please don't let your company interest interfere with the exchange of information that may in any fashion save lives or time because if you blow up the interplay, the time loss is of vital importance today. I'm delighted to be here to see so many of you whom I've seen before and all of those who are coming to their first of these seminars. I don't want to leave this platform, however, without pointing out a fact which many of you doubtless know, that Col. Hamilton who is chairing this session is going to retire at the end of the month. Let's give him something to be very proud of, let's have this one a top-notch session. My greetings to all of you.

Col. Hamilton: We would like to make a few administrative type announcements. The overall classification of the Seminar is Secret. A great deal of what will be talked about today is unclassified. When you do get into classified subjects, please announce the classification. There is no need to take any lengthy notes since minutes are being recorded and in as brief a time as possible after the seminar is over, we will get you copies of the minutes. (Chairman then introduced Members and Alternate Members of the ASESB.) Those of you who have been to previous Seminars know that we usually hear from Mr. Don Miller who is from the Office of the General Counsel, Office, Secretary of the Army. He's here to keep us out of trouble, he's our lawyer and if we start to get into any area where anybody could get the slightest idea that we're about to violate anti-trust laws or anything of that sort, then he'll get up and holler.

Mr. Don Miller, OSA General Counsel: I'm very happy to be here this morning at the 4th seminar and this is the fourth one for me. The purpose of this seminar is to promote free exchange of information relative to explosives safety problems associated with the development, manufacture, handling and use of solid propellants in the various missile programs. The President on February 26, 1962 issued Executive Order #11007 entitled "Prescribing Regulations for the Formation and Use of Advisory Committees" which states that the information, advice and recommendation attained through activities such as this seminar are beneficial to the operation of the Government. The Executive Order prescribes uniform standards for the Government to follow in order that advisory committees shall function at all times in consonance with the anti-trust and conflict of interest laws. These standards have been incorporated in DOD Directive #5030.13 issued April 20, 1962. The Assistant Secretary of the Army has been assigned responsibility for the supervision of the activities of the Armed Services Explosives Safety Board and considers this seminar of great importance and as an additional safeguard in order to provide the maximum possible protection to all participants, he has requested the General Counsel of the Army to furnish counsel. I am assistant to the General Counsel and have been designated to represent the Office of General Counsel, Department of the Army to provide

counsel at this seminar. My primary purpose in attending this seminar is to protect both Government personnel and industry members from inadvertent consideration of any subject which might bring the seminar activities within some aspect of the anti-trust laws. The agenda has been made sufficiently broad so that any matter related to the topics under consideration can be freely discussed. My presence at this seminar is not intended to limit in any manner the full and free discussion of the topics under consideration, but rather to promote discussion. As I mentioned last year, this seminar has been from the very beginning conducted by Chairmen who have had expert knowledge of the various subjects on the agenda and have such a high level of excellence that the full and free exchange of information is readily promoted with complete adherence of the criteria which has been established. Thank you gentlemen.

Col. Hamilton: The next item we have in the book is two talks by Harry Guest and Harry Brinkley. These two gentlemen were mainstays of the U. S. Army Ordnance Safety Agency, formerly the Ordnance Field Safety Office. Through the efforts of these people, that organization was built up and helped maintain the excellent safety record of the Ordnance Corps of the Army. The first one is Harry Guest; he served his apprenticeship way back in the smokeless powder days through about ten years with the duPont Co. and for about the past 28 years he's been with the Ordnance Corps. He has headed up the safety inspection program of the Ordnance Corps. He used to be an Area Ammunition Inspector; Harry Guest.

DO YOU HAVE A COMPLETE SAFETY PROGRAM?

by
Harry C. Guest
Safety Officer
U. S. Army Ordnance Safety Agency
Charlestown, Indiana

In the past few months I have read several articles in national safety magazines and periodicals, dealing with the subject of safety engineering, safety administration and safety management. I have found that most of these articles are based on theory and, therefore, are very difficult to interpret into the day-to-day operation of a safety program. I must agree that looking ahead and theorizing is necessary; however, I also feel that these theories must be translated into more practical terms or they remain only theories and are difficult to use in this form, to establish and conduct a complete and adequate safety program.

When we study the intent or purpose of the safety program, it becomes easier to outline the various phases or elements of this program so that the intent or purpose is satisfied. I think it is commonly agreed that the main purpose of the safety program is to prevent accidents, injuries and property damage. I think it is also true that a successful safety program will produce some desirable by-products, such as

Higher quality products
Reduced production costs
Improved employee morale
And personal pride and satisfaction.

It is important that the intent of the program be continually considered during the planning and day-to-day operation of the program.

It is possible that what I have to say in the next few minutes will not be new to most of you. For some, it might be a refresher and to others it might present some new ideas. I will, however, make one promise, and that is, if you base your safety program on the eight elements which I am going to talk about and, if you feel that you have covered all of these elements in your program, you will have an enviable safety record. I make this promise not as a "guess" but based on the fact that, during the past 10 years, the best safety records of the 90 U. S. Army Ordnance installations with which I am familiar, were obtained by the installations that had a complete safety program which encompassed the following eight elements:

1. Safety Administration
2. Safety Standards
3. Safety Engineering
4. Safety Promotion and Education
5. Safety Training
6. Safety Committee Activities
7. Accident Investigation, Analysis and Reporting
8. Safety Inspection.

Let me break down these eight elements individually and discuss the part each plays in the overall safety program.

1. Safety Administration - Administration is the most important of the eight elements. It links all the other elements together. Two written documents are required in connection with this element -

   a. The Safety Program
   b. The Accident Prevention Plan.

The written safety program must outline management's policies, as to safety, and delegate the responsibilities of the groups and individuals who will carry out the program. It should include the appointment of a Central Safety Board. This Board should have as its chairman the plant manager or equivalent and the Safety Director as secretary. Membership on the board should include all key or staff personnel such as production chiefs, the plant engineer, the fire chief, the personnel officer, the plant doctor or nurse, etc. The duties of the board will be to aid in establishing the safety program and determine its adequacy, effectiveness and methods of improvement. Meetings should be held regularly and minutes should be kept of the meetings. The plant accident experience should be reviewed at each meeting and definite decisions made as to the action necessary to improve the record. This action could include such things as the purchase of special personnel protection equipment, the necessity for changing operational layouts, the need for additional safety training in certain areas and the purchase of guards and safety devices, where required, for operating equipment. The board should review the minutes of the foremen's and employee's safety committees and take any action required from a management level. This action should be decisive and the foremen and employee committees should be notified as soon as possible as to the action taken or why action cannot be taken if such is the case. Easy communication between the management level and worker level is one of the best means to keep a safety program alive.

The program should spell out the duties and safety responsibilities of the Safety Office as well as the safety responsibilities of other staff offices and operating personnel.

For instance, the safety office should be responsible for the co-ordination of the program but other staff offices should be assigned

certain safety inspection responsibilities. The fire department should inspect for fire hazards and also inspect the firefighting equipment; the medical department should assist by checking toxic, radioactive and hazardous vapor exposures; the engineering department should inspect cranes, hoists and lifting equipment and the garage personnel should make safety inspections of the motor vehicle and material handling equipment. This procedure permits the best qualified personnel to perform the inspections in each case. In the case of boiler and elevator inspections, it is necessary to utilize the services of outside agencies that are authorized to make these inspections.

In addition to the written program, there should be a documented Accident Prevention Plan. This is a supplement to the program in that it is a planned schedule of events. It should be prepared to cover a 12-month period and it should be flexible enough to permit changes, if required, due to an adverse trend in operational safety. This plan should establish monthly safety topics based on the accident experience of the plant. It can also coincide with seasonal problems and tie in with national safety drives. For instance, October - Fire Prevention Month; November - Winter Driving Hazards; other subjects that can be used are: Housekeeping, Falls, Hand Tools, etc. This plan should list inspection dates, training periods, committee activities, the posters, film and safety talks on each subject. When planned in advance, sufficient time is available to secure the necessary material to carry out the plan.

It can readily be seen that the administration element of the program insures the interest and backing of management and without this the program will not be successful.

2. Safety Standards - It is impossible to operate any program without specific guidelines. The guidelines for operation of a safety program are the safety standards. Standards must be established before we can design and equip the buildings, before we can lay out the operation, before we can train the personnel and before we can perform routine inspections. General standards have been established by Federal, state and local governments and specific standards by various levels of command. Specific standards have been established by national testing laboratories and other agencies and these documented standards are available for our use. A library of reference material covering safety standards should be available in the Safety Office. This material should be available to the operating personnel and they should be kept informed of changes or additions to these standards. The personnel of the Safety Office must be thoroughly familiar with these standards and by means of education, training and safety meetings keep the operating personnel familiar with these standards. It is realized that not all operations are covered by specific standards. In these cases local standards should be established and approved by the Central Safety Board and management. These now become firm standards and should

be adhered to in all operations. However, the fact that a standard exists is not sufficient reason to assume that operating personnel will comply with the standard. In most cases it is necessary to interpret the standard and explain the reason for the standard. Demonstrations and tests can be used to impress operators that the standard is necessary and that deviations from the standard can result in disaster. We fail in many cases to get the point across when we only explain the "What" and do not show or tell "Why". A very fine library of safety standards is useless until the operating personnel know about it, use it and understand why adherence to these standards is required to insure safer operations.

3. Safety Engineering - This element is concerned with building design, construction and layout of operating facilities, operating machinery and equipment, tools and the materials that are used to produce the end product. In other words, this element deals with the areas in which employees work, the equipment and tools they use and the materials on which the work is performed. Although the safety office can be of assistance in interpreting the safety standards, I firmly believe that the engineering department should be held responsible to insure that the job is properly engineered from a safety standpoint. Most large plants or companies are blessed in that they have available the services of qualified and well trained engineers. In smaller companies, it may become necessary to call in engineering consultants. In either case, the safety office should assist the engineer in insuring that the safety standards are included while the job is being "engineered." There are cases on record where the failure to include the engineering element in the safety program resulted in financial losses and production setbacks. Buildings have been designed and constructed with insufficient exits for the number of people working in the building. Provisions for ventilation and lighting have been inadequate. The improper location of permanently installed equipment has adversely affected the safety of operations. This element should cover such other areas as machine guarding, the type and design of special tools and the personnel and fire protection required where special materials are used namely radioisotopes, large quantities of flammable and toxic materials. Coordination between the engineering department and the safety office can pay large dividends in reducing the accident potential and it is therefore important that this element be stressed in the safety program.

4. Promotion and Education - For the purpose of the safety program, it is necessary to understand the difference between this element and the training element. The promotion and education element covers mainly the advertising and publicity of the program. The training element involves formal training with specific groups at specific times and conducted by qualified training personnel. The promotion and education element is generally composed of the use of safety posters, the passing out of safety literature, such as the safe driver, safe

worker, memorandums on specific subjects inserted in pay envelopes, etc., contests of all kinds and safety awards. There are several schools of thinking on the use of some of the tricks or gimmicks under this element. For instance, some safety personnel question the value of using safety posters. Other safety personnel feel that safety awards do more harm than good. I have no intention of taking a stand on these "pros" and "cons." I do contend, however, that the secret of the success of any program depends on whether or not all employees have a definite interest and take an active part in the program. By the laws of human nature every individual seeks and desires to be recognized.

I have a definite feeling that the success of a safety program is directly related to the recognition of each employee. The best way to carry out this recognition is to give him a part of the program. For example, each employee in a carpenter shop can be assigned certain safety responsibilities. For a given period of time one man can be required to check all machine guards, one man can check electrical equipment, one man can check the adequacy and use of personal protective equipment, one man housekeeping and so on.

This element, however, can have an adverse effect on the program. A promotion scheme may be successful at one installation but a complete failure at another. An awards program, if improperly handled, may make a few employees happy while at the same time turn the majority of employees against the overall program. The improper use of posters and educational material in some cases has created a loss of interest in the program. The safety office must give a lot of thought to the use of this element to insure that it performs its mission of creating and maintaining the interest of all employees in operational safety.

5. Safety Training - As previously stated, this element differs from the promotion and education element in that it has to do with formalizing training. Its purpose is to teach all levels of supervision and working personnel the what, when, where, how and why of safety. It insures the orientation of new employees, provides for on-the-job training, especially when employees move from one job to another. It permits a continuous follow-up to insure that each employee is familiar with current safety standards and changes to standards which improve operational safety. To insure its effectiveness, this element should be planned in advance and covered by a written schedule. The written schedule should include what training is to be given, who will give the training, the time and place it will be given and which employees will attend. Safety training schedules should be based on the accident experience of the plant and should be flexible so that it can be quickly adapted to cover those areas where an adverse safety trend is indicated. Some of the important points of this element include: use only well qualified and capable instructors, include some safety in all training programs and closely adhere to the pre-arranged training schedule.

6. Safety Committee Activities - There should be at least three levels of safety committees:

The Central Safety Board
Supervisor's Safety Committees
Employees' Safety Committees

To be of any value, these must be working groups; by that I mean, each member must plan an active part in the activities of the committee. Safety committees perform two very important functions in the overall safety program:

a. They establish a direct communication from the worker up to management and from management back to the worker.

b. They create individual interests in safety.

Operating properly, committee activities permit safety problems which originate at the worker level to flow up to the supervisor's committee and then if necessary up to the Central Safety Board and management. This procedure then permits management to quickly return, to the worker level, decisions to solve the problems and also to disseminate safety policy. Any committee where the chairman dominates the meeting and performs all the work does not accomplish its mission. Committee members should be assigned various duties and should be required to make studies of conditions which present occupational hazards. These studies should include recommendations as to the best method to correct the unsafe condition. In summary of this element, committees should be active, they should coordinate with other committees and, at the operator level, the members should be rotated so that all employees serve some time on a safety committee.

7. Accident Investigation, Analysis and Reporting - This element is the thermometer of the safety program. It provides for the gathering of facts so that any weakness in the program can be detected and corrected. It makes it possible to quickly adjust the program to overcome adverse trends and it gives a basis for the types of training, engineering or inspection that are required in the future. I realize that in many installations the number of accidents is so small that they do not indicate any trend. It is therefore important that all of the following be covered under this element:

Fatalities
Lost Time Injuries
First Aid Cases
Sick Leave
Mild Illness Complaints (environmental health)
Property Damage
Near Misses.

Just the fact that all of these unplanned events are investigated and reported does not insure that accident rates will improve. The important point is the analysis of the findings and action taken to correct the causative condition.

My experience indicates that much time is spent in accident investigation and making out voluminous reports for file but very little time is used to analyze the condition and prepare and follow through on documents that will correct the condition. It is known fact that in many cases the employee does not cut off his hand or break his leg the first time he performs an unsafe act or does his job in the vicinity of an unsafe condition. Bruises, slight cuts, splinters, sore backs, etc., indicate that the law of averages will take over soon and more serious lost time accidents and fatalities will follow. Investigation and analysis performed correctly and in time will often beat the law of averages.

8. Safety Inspection - From my experience in the safety field, I firmly believe that this element has the greatest results in the success of the safety program when it is conducted properly. Normally, the mission of performing safety inspections is assigned to the Safety Department and, therefore, results in this department becoming a spying agency with some enforcement responsibilities. I believe that the Safety Department should be a staff agency reporting directly to the top management official. The main mission of the Safety Department should be to keep the top official advised as to conditions safety-wise throughout the plant or installation. This department should provide safety technical assistance to the operating sections and coordinate the entire safety program. They should be responsible to insure that all the elements that I have discussed are functioning properly. And finally - their safety department should have no enforcement responsibilities. There is a tendency for the safety department to get into the operating details of the various jobs and consequently the safety responsibility of the supervisor, foreman and the operator have been lessened to the point where we hear the operating personnel make the statement "that is the responsibility of the safety department." I feel that the day-to-day safety inspections should be performed by the operating personnel and the safety department should make spot checks only to insure that operators and foremen are making thorough inspections, and so that management can be kept informed as to conditions throughout the plant. Until we can get all supervisors, foremen and operators to assume their safety responsibilities and make this a continual requirement of their jobs, we cannot expect to have accident-free experience. I personally would like to see a safety clause in every job sheet which is evaluated on every individuals' efficiency rating. With further reference to safety inspections, there are well qualified personnel at each plant that can best perform certain inspections in cooperation with the safety department. For instance, the

Health and Medical Department can inspect hazardous areas involving toxic, fume and dust exposures. Who can better perform fire prevention and protection inspections than the fire department? The plant engineer group can inspect heavy lifting equipment such as cranes, hoists, blocks, slings, hooks, etc., and of course, the garage mechanics should inspect the rolling equipment, such as vehicles, material handling equipment, rail transportation equipment, etc. And finally, our biggest error is, in the fact, that we have not convinced supervision that they must continually inspect their own operations rather than feel this is a mission of the safety department only. By following this procedure, we can now put the safety department on the staff level and thereby permit them to utilize their time in formulating and coordinating the overall safety program. Another problem encountered in this element involves the assignment of extraneous duties to the safety department. It is difficult to believe, but there are actual cases where the safety department has been assigned to the following additional duties - security, chairman of Red Cross and Community Chest drives, operation of cafeterias and snack bars, recreational activities, public relations office and others. Management displays a lack of interest in the safety program when it saddles the safety department with these extraneous duties. The qualification and training of the safety department personnel are also important items under this element. In my many years in Civil Service, I have always understood that the practice of using personality as one of the qualifications for employment was frowned upon. This is an important qualification for personnel in the safety department and should certainly be given some consideration. Further, the age old argument as to whether the job requires an engineer has its importance in the hiring of safety personnel. It appears that there is no hard-fast rule; however, if the department operates at staff level it would follow that administrative experience with managerial background would be most important and should be coupled with some engineering experience and a good personality and common sense. Safety personnel require continuous training and contact with other plants and professional groups. New materials, techniques and protective measures which are being devised and used by industry make it necessary for safety personnel to keep up to date. Here are several ways that we can improve our knowledge. Correspondence courses, night schools in adult education classes, subscription to pertinent publications. Membership and attendance at professional group meetings and contact with other companies with similar operations. Work in the safety field is considered to be a profession and it behooves all safety personnel to continually improve their position in this field.

This element requires a written inspection schedule. There must be some planning as to who inspects, where they inspect, when they inspect and a system of reporting and follow-up must be used to insure that this element is completely performing its mission. Most important,

inspection must have a basis, not just inspect for the sake of inspection. This basis is usually accident and first-aid case experience, hazardous operations and where supervisory personnel indicate a tendency to deviate from safety standards. In some cases it is possible to plan the safety program from the results of safety inspections.

9. Summary - In summary, let's take another look at the eight elements and review the high points of each element.

First - Administration should be covered by two written documents -

a. The Safety Program
b. The Accident Prevention Plan.

This element outlines management's policies and delegates responsibilities. It establishes the Central Safety Board, and provides command backing for the entire program. I place it first because it is the most important element.

Second - Standards. This element provides the guidelines, requires a safety library and includes the rules and regulations on which the program is based.

Third - Engineering. It should provide for built-in safety, as it pertains to the building design, layout of operations, machinery, equipment and tools to be used and the materials required to perform the operation.

Fourth - Promotion and Education. This involves the advertising and publicizing of the program. Contests, awards, etc. Some ideas work - some do not. This element requires much thought and care in its use. Improperly handled, it can hurt the program.

Fifth - Training. This element should be covered by a written schedule. Some safety should be included in all training programs. All personnel should be included in the safety training program. More of this element can be used in every program.

Sixth - Committee Activities. There are three:

a. The Central Safety Board
b. Supervisor's Committees
c. Employees' Committees.

They must be working groups and must have specific objectives. This element provides immediate communication between management and worker.

Seventh - Accident Investigation, Analysis and Reporting. The thermometer of the program. Thoroughly analyze the information gathered during investigation. Investigate and analyze all unusual events. Use the information to strengthen the safety program.

Eighth - Inspection. This is not entirely a function of the safety department. Other agencies should help. Inspection personnel should be well qualified. There should be a written schedule. Do not assign extraneous duties to the safety department. Have some basis for the inspections to be conducted.

I have discussed eight elements that I feel are essential to an adequate safety program. You may think of others - use them! If I get only one point across to you today, I would like it to be the fact that, unless the worker and his supervisor have an active part in safety and realize that they are the ones who are responsible for safety - we can never have an effective safety program.

I also know that no matter how good a program you have, how well it is documented, how safety-minded all personnel are, there are times when it seems that the bottom falls out. In this case - all I can tell you is to stick with it - do everything you can, but do not give up.

As you can see, the angles and facets of conducting a safety program are voluminous. A failure in the program shows up immediately in injury - death and property damage. Would it not be wonderful if with a successful program we could say - "Last week we prevented a fire here and last month we prevented a fatality at this location." Safety is the one profession that requires continual and close attention to the job - with obvious and disastrous failures and inconspicuous success. And since you need the presence of one other element - I will now supply that - GOOD LUCK

Col. Hamilton: The other Harry is Harry Brinkley from the Ordnance Field Safety Office. He's had 30 years experience in this explosives game, the last 11 years he has specialized in investigations of explosives incidents. He took a lot of the earlier work which had been done up until about 11 years ago and added to the techniques then available. He went to the Arson Investigators School and studied investigating techniques. To my knowledge, he has investigated more explosive incidents than any other man in the country. There's no explosive incident of any consequence that's happened in the Army during the last 11 years that hasn't been investigated by him and he's investigated some of those that happened in contractor's plants. He can make Sherlock Holmes look like a piker when it comes to looking at a crater and actually coming up with evidence as to what happened. Harry Brinkley.

ACCIDENT INVESTIGATION

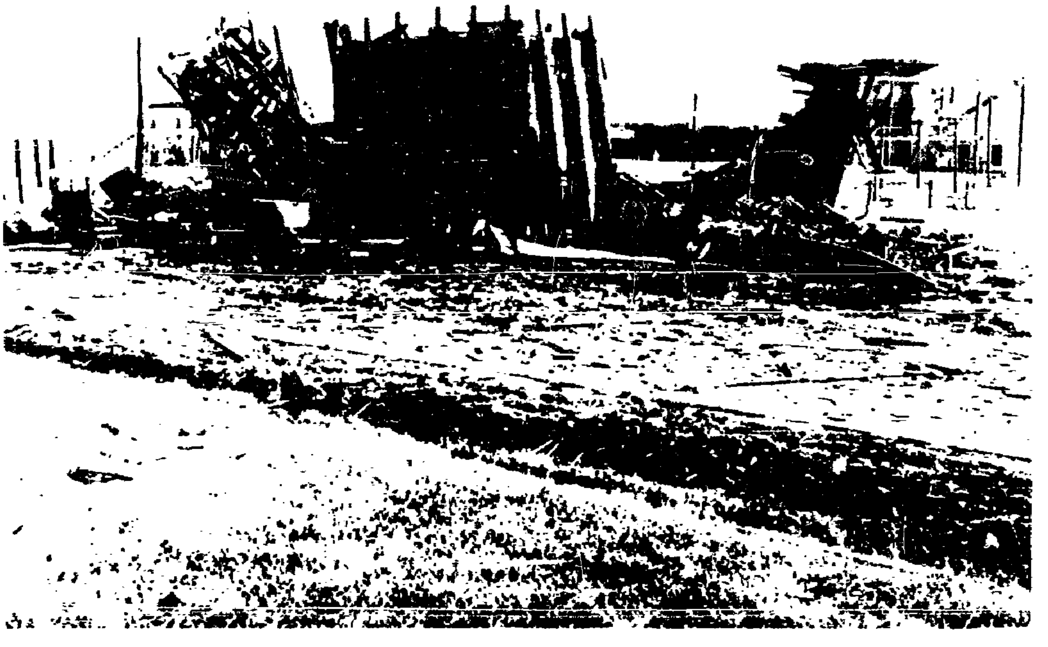
by
Harry L. Brinkley
Safety Engineer
U. S. Army Ordnance Safety Agency
Charlestown, Indiana

The philosopher tells us that the future depends to a large extent on what we do about the past. There is no area where this is demonstrated any more dramatically or graphically than in the field of safety - particularly explosives and propellant safety.

We don't realize the impact of a costly explosion or fire until it involves the operation for which we are directly responsible, and personnel we know, our company, or our installation - and our own careers.

During the past ten years over 1,000 explosives type accidents have been reported to the U. S. Army Ordnance Safety Agency. These accidents were investigated, studied, evaluated and publicized to interested establishments.

Our investigations requires us to visit accidents like these:



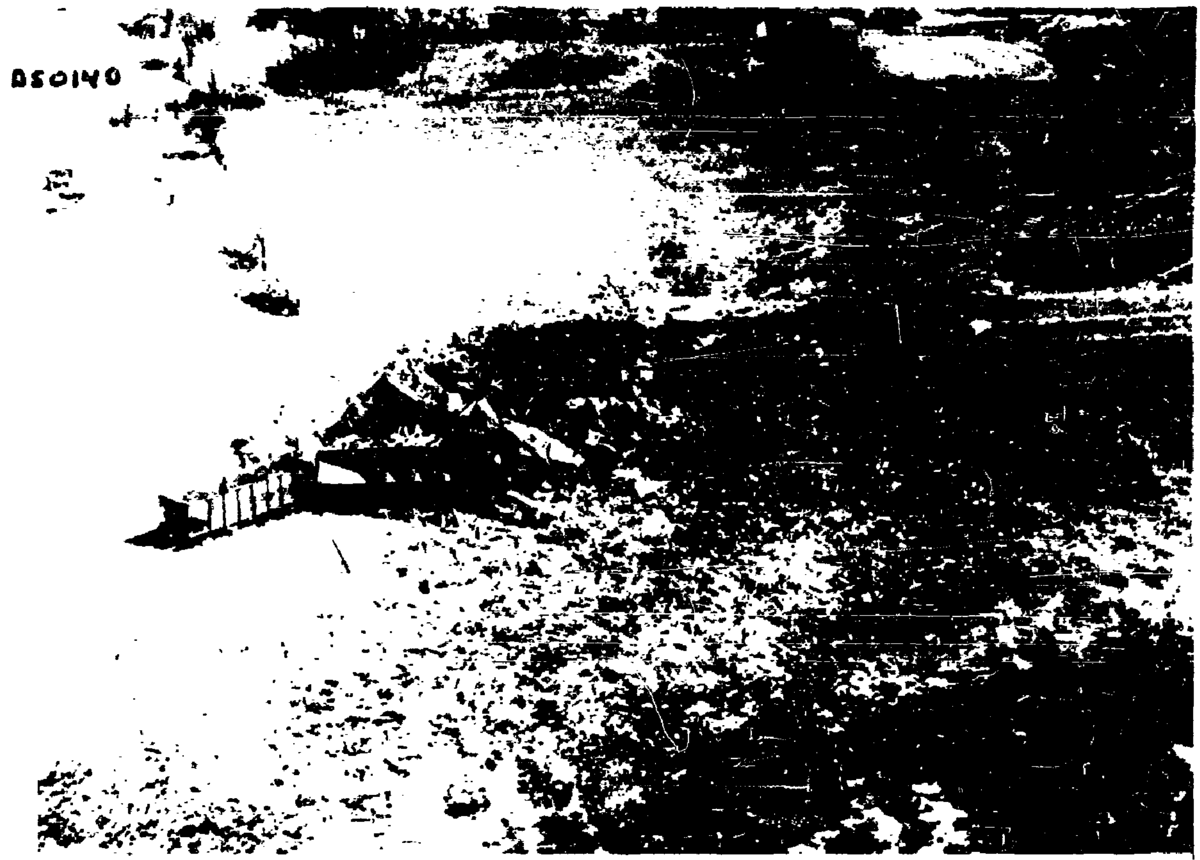
Slide 1
Explosion - Propellant Blending Building

The explosion which resulted in the loss of this propellant building cost the Government $200,000 and thousands of pounds of propellant.

Slide 2

Fire - Explosions - Igloo Magazine

This explosion involving 185,000 pounds of propellant occurred at midnight. Eight hours later a crew would have been working in this magazine.

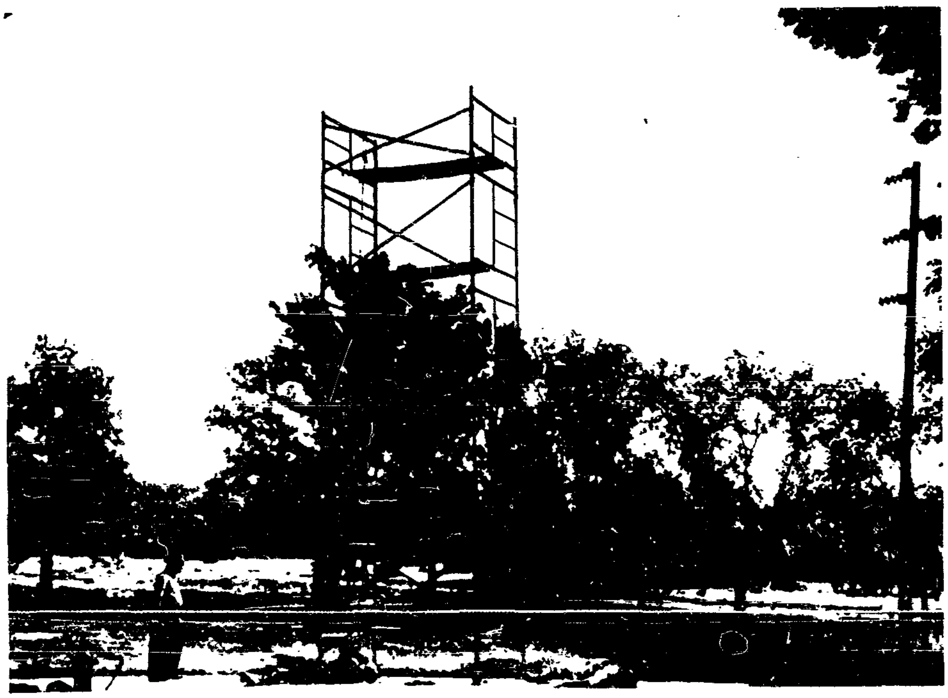


Slide 3

Fire - Explosions - Railroad Cars

This accident involving a common carrier resulted in the explosion of two cars of high explosives and one car of artillery shell. Ninety-five of the 100 homes in the adjacent town were destroyed or damaged. Fortunately there were no fatalities.

Our accidents are not always explosive.



Slide 5

Electrical Accident - Electrocution

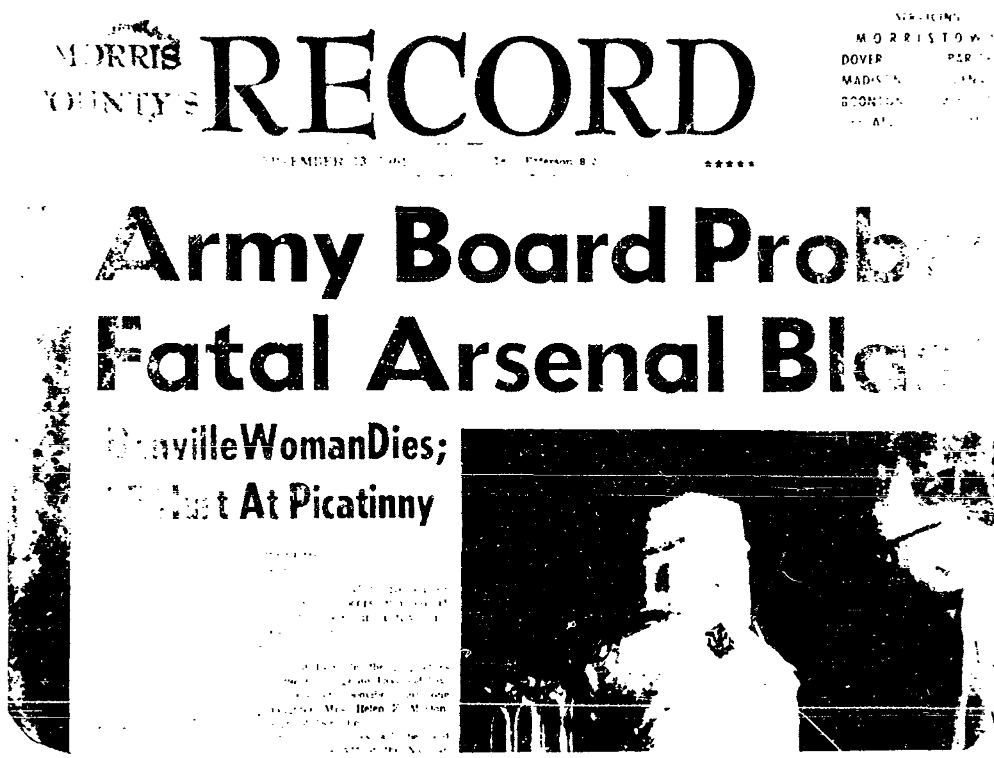
These two men were electrocuted when the metal scaffold they were moving made contact with a 33,000-volt power line which crossed over the road.

Sometimes they are gruesome.

Slide 6

Fatality by Burning

Here is a point that should be made. Almost every newspaper carries daily details of traffic deaths. These stories seldom make the front pages. In fact, they have become so commonplace that they are hardly considered as news. But when people are hurt by an explosion, especially if it occurred at a Government installation, most times the accident will receive publicity all out of proportion to its severity or seriousness.



RECORD

Army Board Pro

Fatal Arsenal Bl

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t At Picatinny

Slide 8

Newspaper Headlines

Note the big headlines about the explosion. Sure there was a fatality and several injuries, but on that same day - and on the back page of a newspaper -- I found a story about an auto-truck crash in which four people were killed and several others were injured. The headlines were hardly noticeable.

Now we must guard against this concept. All accidents must be carefully investigated, if we mean what we say about accident prevention.

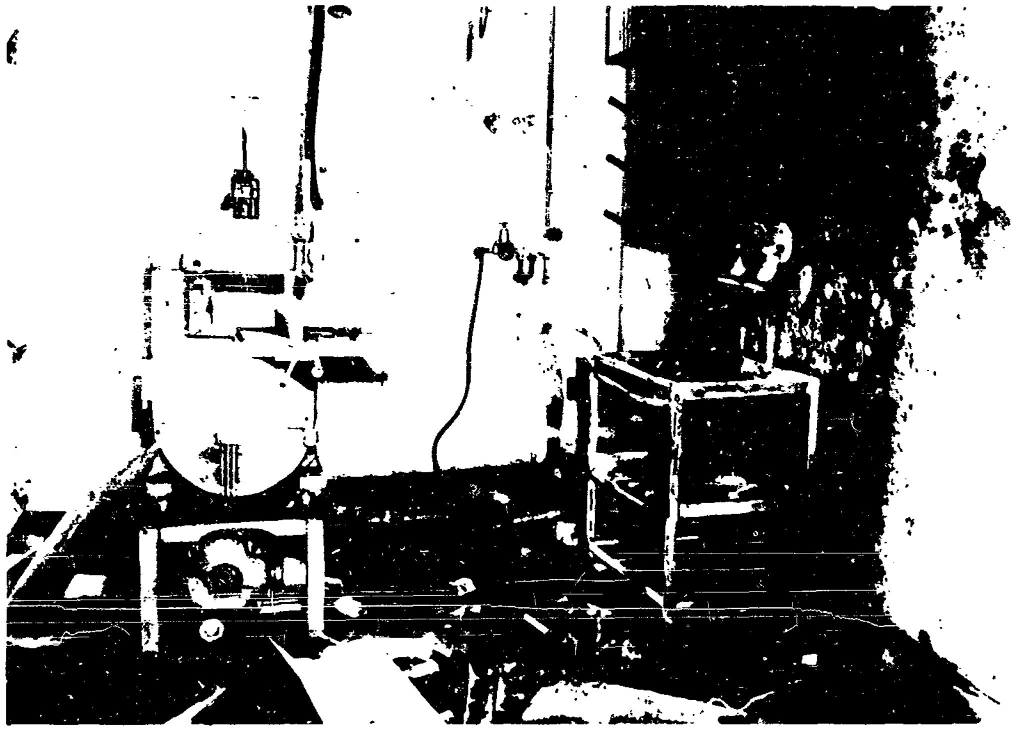
At this point I am going to anticipate one of your questions. Why all the emphasis on explosives safety when less than five per cent of the Ordnance Corps accidentssare in that category?

Here's why: Ammunition and explosives are designed for one purpose - to destroy - to destroy people and property. The first mistake around explosives items is often the last mistake. All operations involving ammunition and explosives are filled with risks - risks to life, property and perhaps the position of our country in the world struggle. We can't afford to take a chance. We teach our safety personnel to expect the worst, and then they will never be caught unprepared. But let's get back to the subject of investigation.

The true purpose of accident investigation is to find the causes of the accident so prompt corrective action can be taken. Each accident that occurs is an indication of something wrong. We want to find out what it is.

It is said that experience is the best teacher. Everything we know has been taught to us through experience - either our own personal experience or someone else's. We can gain the benefit of the other fellow's experience through hearing him tell of it or by reading it. Safety personnel are always anxious to increase their background experience in the realm of accident prevention. Any accident of your own installation quickly adds to your knowledge, but you get the biggest dividends with less pain and embarrassment from reading of accidents at other places.

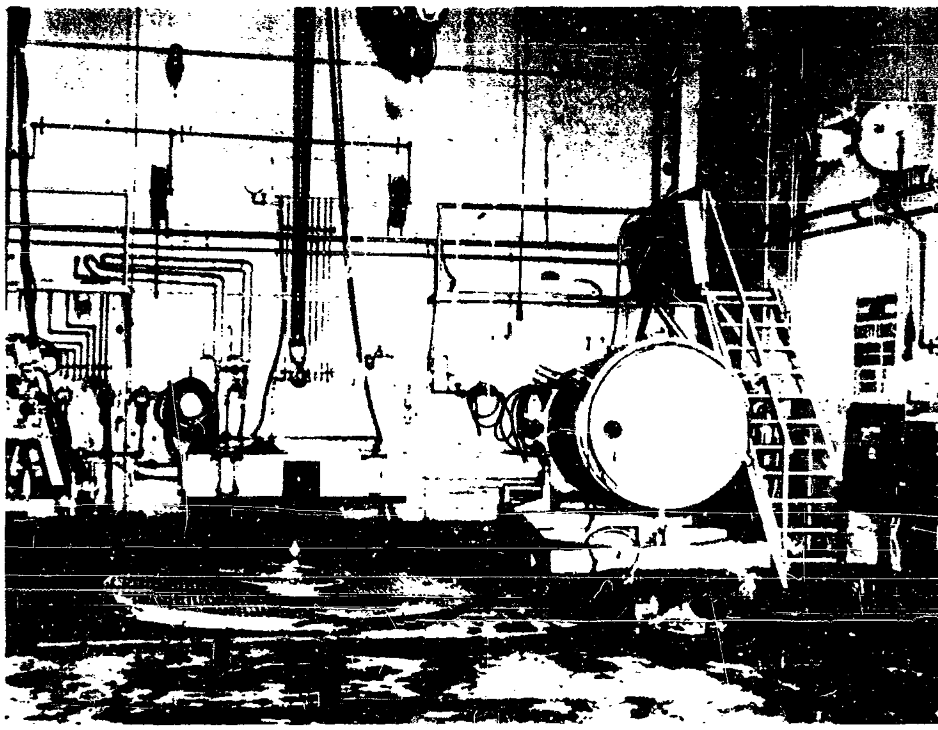
Lets review some of our experience --



Slide 9

Explosion of Vacuum Line

Less than two months ago a man died at this location. He was cutting composite propellant samples with a band saw when an explosion occurred in the vacuum line. Management was to provide remotely controlled equipment at an early date. "TIME RAN OUT."



Slide 10

Fire in Casting Can

An operator entered this casting can to scrape and remove the propellant. The propellant ignited and the operator was blown 20 feet. Fortunately the can opening did not face the cubicle wall. We are glad to report "NO FATALITIES."

Slide 10A

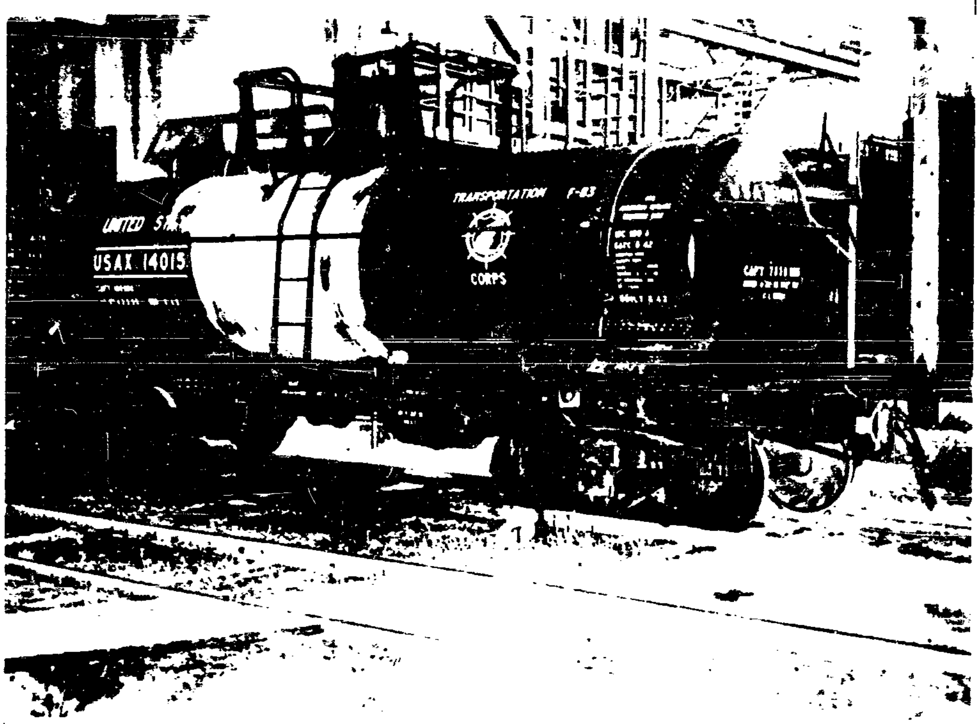
Fire - Curing Building

The fire which resulted in the loss of this rocket propellant curing building cost the Government $200,000 and thousands of pounds of rocket propellant. We failed to anticipate the worst; however, we learned a great deal from this accident.

It would also be beneficial to every safety man if he could read all the accident reports that are received in the Ordnance Safety Agency. He would be surprised by the number of "repeater" accidents occurring at one installation which are almost duplicates of previous accidents at another establishment. He would be even more surprised if he could know the number of times a "no-damage" or "no-injury" accident has occurred on an operation before a bad one came along. It is not

uncommon when investigating an accident to hear this statement: "<u>We have been doing it that way for a long time and nothing ever happened</u>!"

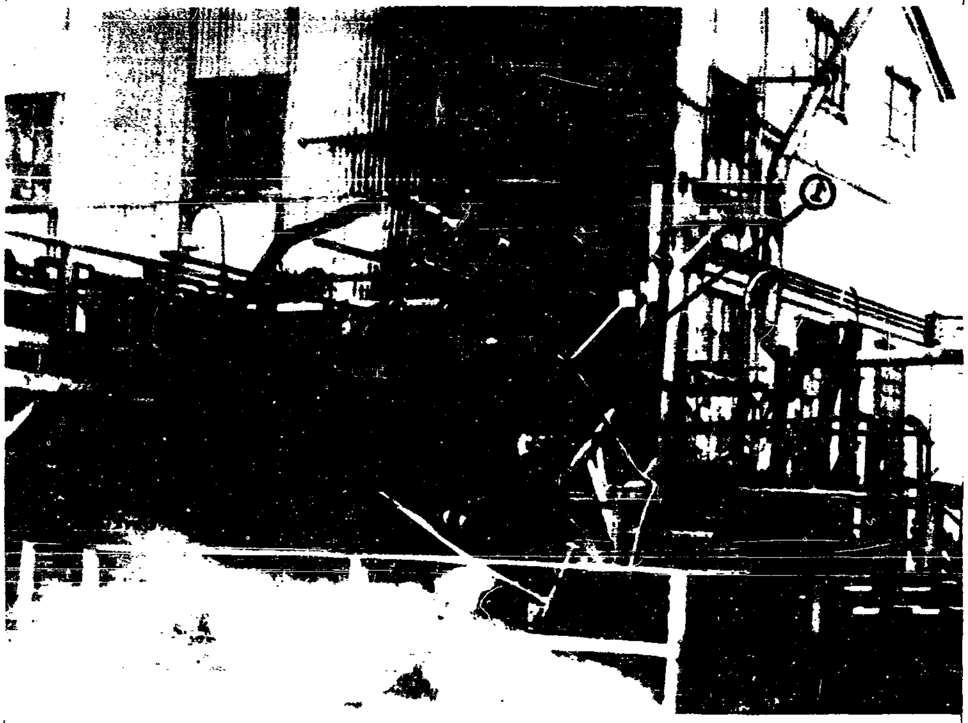
Accident-free time is no guide for safety of operations. Time will run out someday and the law of averages will exact its toll. Let me show you what I mean.



Slide 11

Acid Spill From Tank Car

The operator preparing to take acid samples died at this location when sprayed with acid. He was performing an operation which had been conducted for 15 years without an accident. He failed to vent the car of acid before removing the cap from the stand pipe.



Slide 13

Explosion - Acid Tank

A man lost his life at this location when the acid tank exploded as he gauged it. No accident of this type had ever occurred at an Army installation. Investigation revealed that a sensitive explosive chemical was accumulating in the bottom of the acid tank as a by-product. The arrow points to the location where the operator was found.

Slide 14

Explosion - Contaminated Pipe

Two men lost their lives in this salvage yard when they applied a blow torch to cut a pipe. They had performed the same operation hundreds of times without an accident, but somehow a pipe filled with explosives got into the yard. Exposure to the elements had erased the identification markings. Ten additional lives would have been lost if this accident had occurred several minutes previously.

Slide 15

Explosion - Burning Ground

This resulted from the detonation of several hundred pounds of explosives at the burning ground, which resulted in four deaths. The same operation had been conducted for 20 years without an accident. There were no survivors to tell what happened.

Accident-free experience is all the more reason why we should be on guard to detect and eliminate potential hazards in the operations for which we are responsible.

Accidents have no favorite targets; however, they thrive and multiply on unsafe conditions and unsafe acts. Our inspections and investigations are directed toward the elimination of unsafe acts and unsafe conditions. Consequently, it follows that if we have investigated and inspected properly, we have no excuse for the "repeat" accidents - but we still have them. They involve:

1. Processes.
2. Equipment and Facilities.
3. People (whether they be scientist, engineer, technician, supervisor or worker).

And the results of a "repeater" are the same as those of a first timer - tragedy and probable loss of production and equipment - plus proof that we didn't learn anything from our previous experience.

Our Agency studies these problems and "repeat" areas. We have to, in order to maintain our present excellent safety record. It is to be noted that the Ordnance Corps suffered no deaths from fire or explosives during FY 1961 although there were some close calls. We cannot say the same for FY 1962.

Investigations and studies reveal these to be some of the major causes of our accidents:

1. Inadequate protection for personnel.
2. Lack of sufficient safety training.
3. Increase in explosive potential and sensitivity of new chemicals.
4. Use of outdated equipment and facilities.
5. Poor liaison between R&D laboratories.

Some may say, "But that wouldn't happen at our installation." For those, I will let experience speak for itself. I am going to show you accidents in several problem areas which have resulted in death and/or destruction. You can draw your own conclusions.

Research and development activities throughout the Ordnance Corps accounts for many accidents each year.

However, research and development will continue. It is our life blood. Without it, we will dry up and cease to exist as individuals or as a nation.

Nevertheless, many universities and colleges are training men for research and development work without including safety. What good is knowledge if we commit suicide through lack of safety consideration?

The following pictures are grim reminders of what can happen - and if it can - it will.

Slide 17

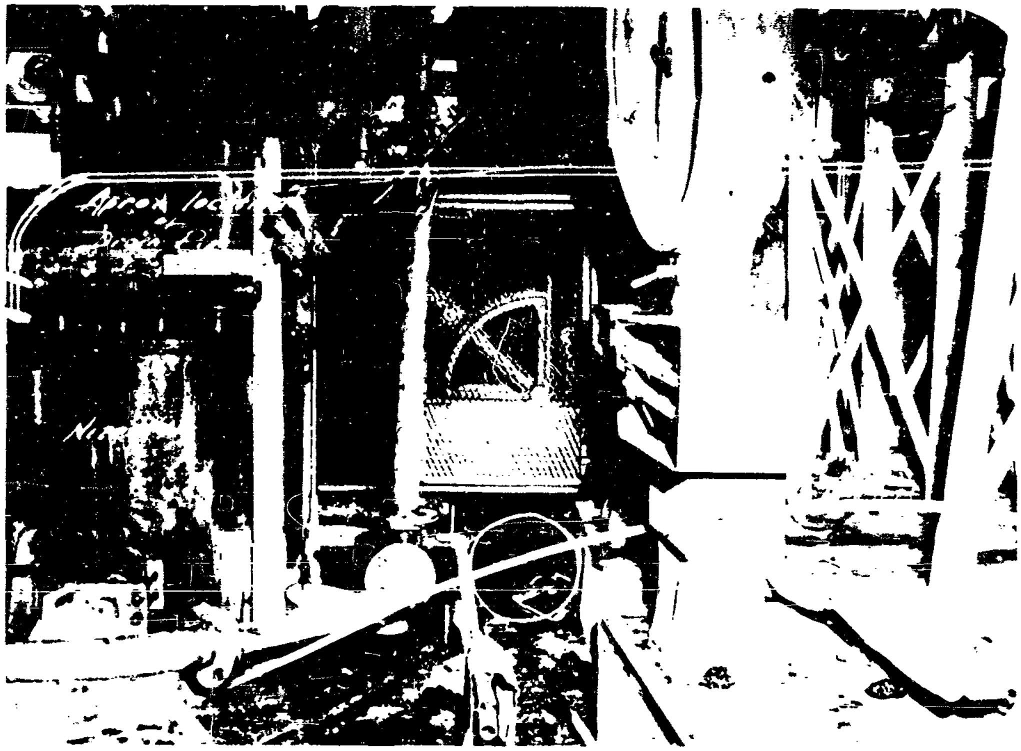
Explosion in Test Stand

An explosion occurred several seconds after an attempt to ignite the motors of a missile. A young engineer died behind the destroyed concrete wall of this test stand. Management failed to anticipate the explosive potential of the chemicals involved.

Slide 20

Explosion in Rocket Press

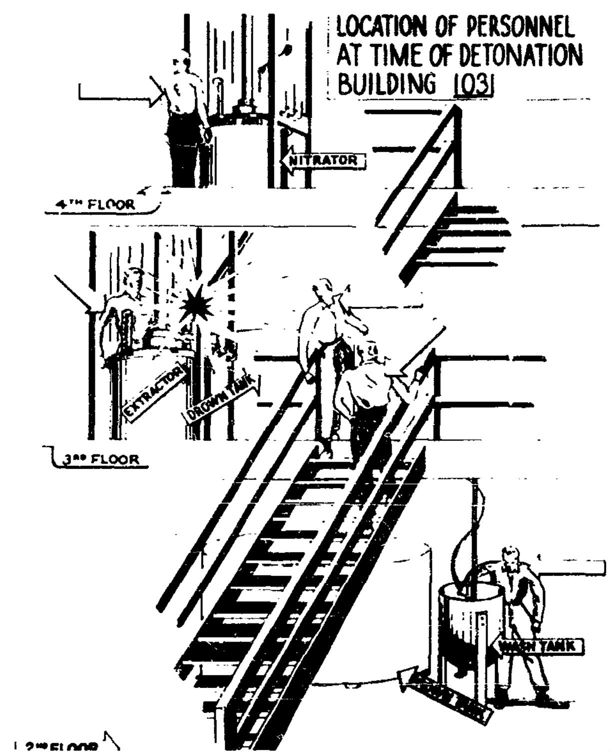
This explosion occurred as rocket propellant was being extruded on a research and development project. Equipment was also experimental. There were no injuries as operation was by remote control.



Slide 21

Explosion During Nitration Process

Explosion of a sensitive chemical which had collected in a drain line caused one fatality and several injuries. Washing of the drain line failed to remove the sensitive chemicals which exploded from a chemical reaction. Note position of the drain line.



Slide 22

Position of Personnel

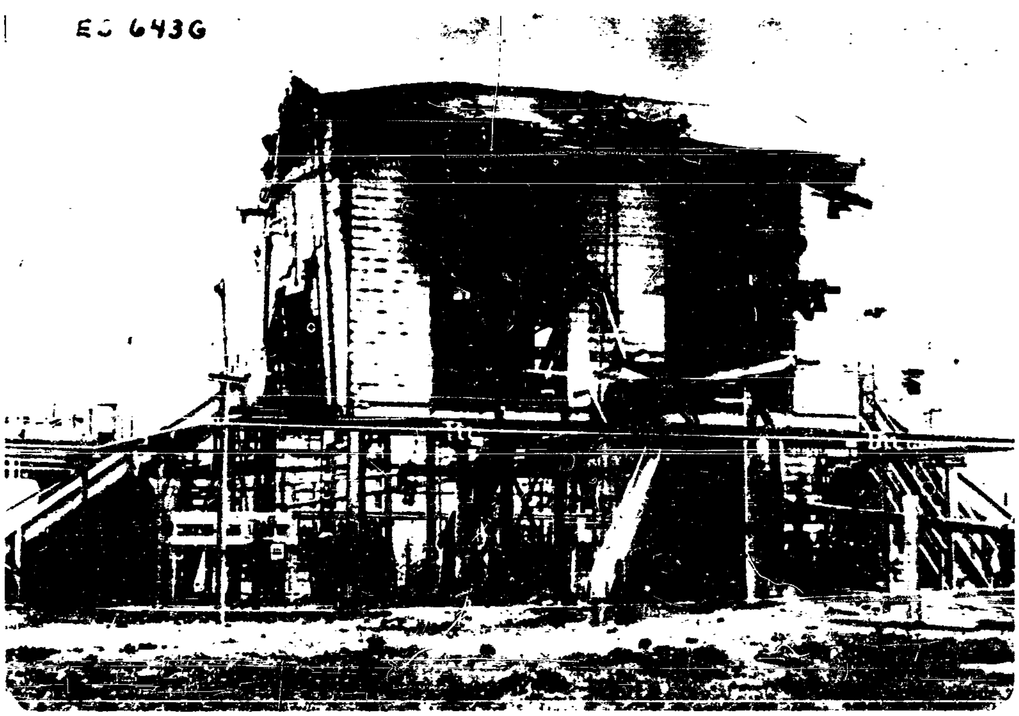
Observe the position of the personnel assigned to this Research and Development project at time of the explosion. Only chance was the difference between life and death.

It is quite obvious that the safety staff must work very closely with the R&D people - even more closely than with production activities, because of the non-routine, non-repetitive and unknown aspects of research and development operations.

Every man is aware of his own safety attitude and what his accomplishments have been promoting safety. He must assure himself that the operations for which he is responsible are conducted in a safe manner and that personnel are protected against the unexpected. That is the area where we are prone to adapt a false sense of security.

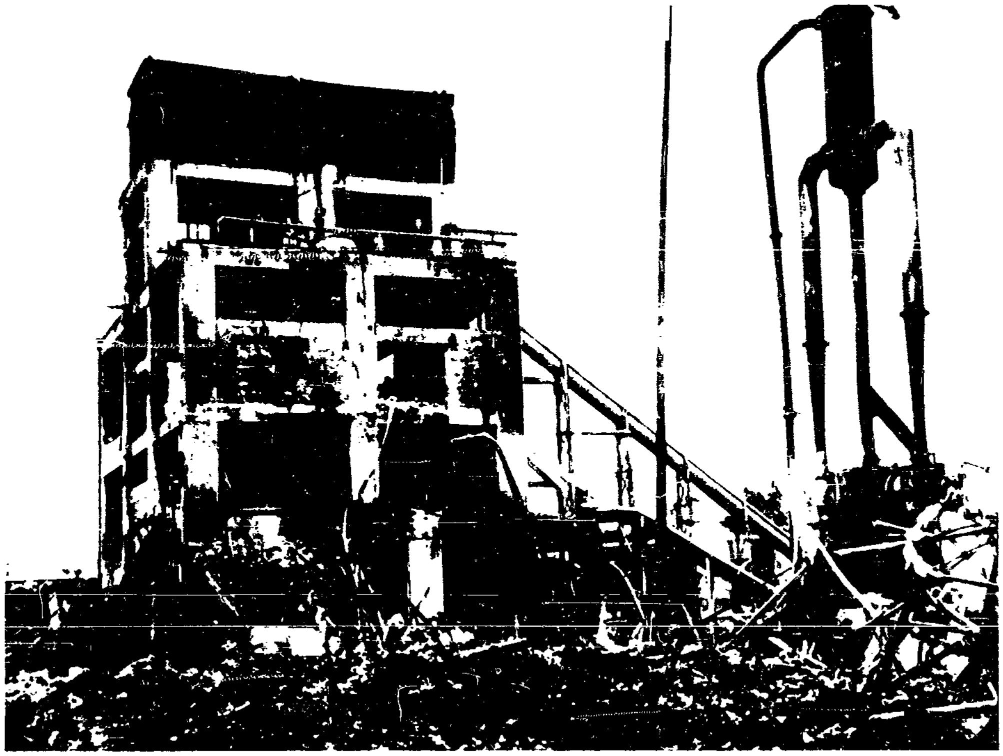
Sometimes we lose our facilities and equipment because of human error. In spite of our progress in designing accident prevention features into our equipment and facilities, people still cause accidents. Man's behavior cannot be accurately predicted in any given circumstances. Let me illustrate.

E. 643G



Slide 29 - Fire and Explosions

This tri-nitration bldg. suffered extensive damage when the operator failed to activate the agitator. Excessive fuming followed by fire and explosions occurred when a chemical was added to mixed acid.



Slide 30

Explosion - Nitrating Building

This slide shows a large explosives processing building that went out of production. A series of explosions involving several thousand pounds of explosives occurred. This accident cost $300,000. Investigation revealed that an open valve which permitted an acid spill was tne cause of an initial fire which resulted in a series of explosions.

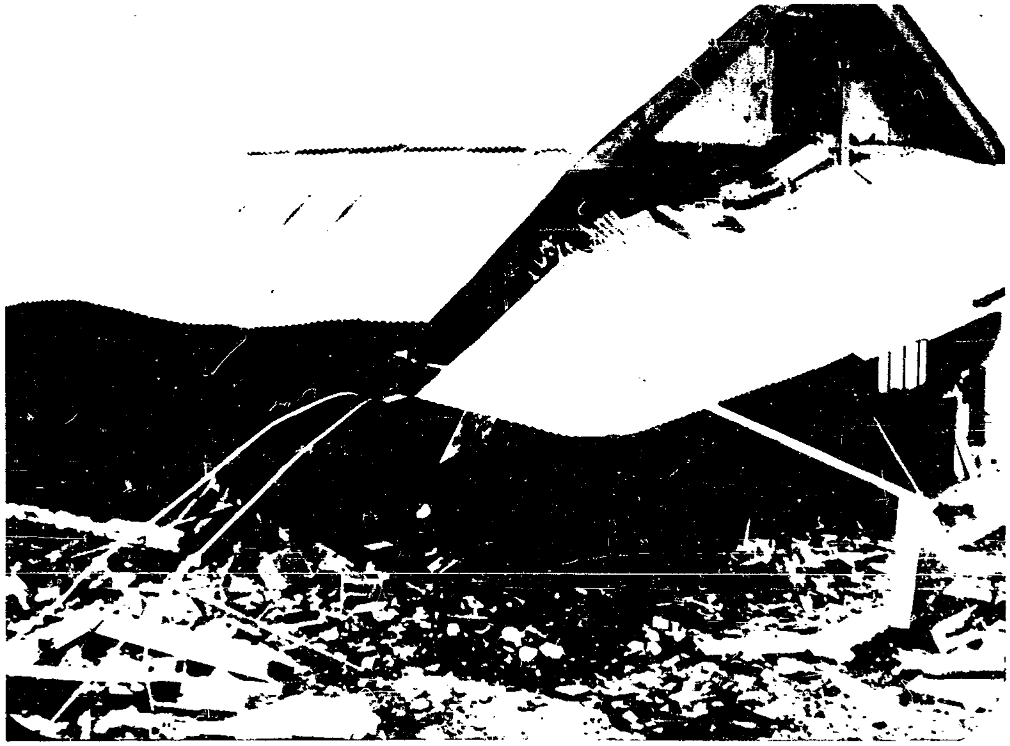
Army personncl are aware of the deadly potential of explosives items being processed. They also know that an accidental explosion can destroy the facilities and injure and kill employees assigned to the operations. As proof that they realize these facts, operations that jeopardize the safety of life and property are isolated. In addition further protection is given through the use of reinforced concrete walls.

Over the past several years a number of explosions involving dividing walls have occurred at Ordnance installations and at privately-owned, privately-operated plants with Government explosive contracts. Investigation of these accidents revealed deviation from design or construction principles that were essential for the safety of personnel and protection of property. Let's look at this problem area.

Slide 31

Explosion - Pelleting Building

Fifteen pounds of high explosives caused this damage. The substantial dividing walls did not effectively separate operating cubicles. The roof was continuous and the blow-out wall of heavy tile.



Slide 32

Explosion - Laboratory Mixer

A small amount of explosives (approximately two pounds) but a lot of damage. The exterior "blow-out" walls were constructed of heavy material - hollow tile.

Slide 34

Explosion - Photoflash Composition

This photograph shows the extensive damage done when five pounds of pyrotechnic composition ignited in a hopper. The construction was substandard.

Slide 35

Explosion - Primer Mix

The open doorway in the room and the continuous roof increased the extent of damage and compromised safety of personnel in other sections of the building.

When processing explosives, the possibility of an explosion or fire is always present. Therefore, the safety of personnel and property is a must. There can be no compromise of safety. It is mandatory that safety be built into the facilities designed to protect life and keep property damage to a minimum.

The safety requirements to accomplish this must be determined in advance and the operating procedures conducted in such a manner that the facilities are utilized to offer the maximum protection.

All skilled explosives safety people will agree that it takes a vivid imagination to predict the series of happenings that might lead to a possible explosion or fire - but such vision, plus accident experience, plus training and know-how are the necessary factors that enable them to "foresee" accidents. Even then so-called "unforeseen" accidents sometimes occur.

Let's take a look at a few typical statements taken from the reports of some explosives accidents that should have been foreseen. Here is a statement: "The helper had taken over the operation during the temporary absence of the trained operator....."

Slide 36

Explosion Complete Round Gage

When the trained operator returned, he failed to see the complete round left in the gage by the helper. He struck the primer of the round and two persons died!

Here is another statement: "Ordinarily there would have been only five men at this location. The other seven persons were not authorized."

Slide 39

Fire - Tetryl in Screening Building

One man lost his life when this high explosives screening building caught fire and destroyed 15,000 pounds of explosives. A detonation instead of a fire would have resulted in 12 fatalities.

A concluding statement: "This was the first day the trainee was on this operation. The regular operator was off."

Slide 40

Explosion - Gaging

Four persons lost their lives when the primer of the complete round of ammunition was accidentally struck and functioned. The shell also detonated. The first day was also the trainee's last.

If any of these situations are permitted to exist, it is illogical to say that the accident was "unforeseen." Saying it the other way around, such unsafe circumstances and practices will sooner or later lead to an accident, and must not be tolerated.

What can we - or should we do about it? A study of these unsafe situations will convince the investigator that they can be prevented by operating procedures that are complete and adequate and by the caliber of supervision that will control operations and employees so that only the proper things are done - efficiently and economically, which means safely.

We recommend the following actions with the feeling that they will help the situation materially:

1. Be sure that your operating procedures do not contain a hidden source of danger - one that you haven't suspected.

2. Let your operating procedures be reviewed by people with long experience in explosives and industrial operations - and make such review a constant effort.

3. Immediately incorporate into your operating procedures the things learned from an "unforeseen" accident, near accident or sudden discovery of a potential hazard by an operator or supervisor - thus, making a benefit out of a possible catastrophe.

4. Make certain that all employees and supervisors assigned to hazardous operations are adequately trained and are fully aware of the inherent hazards of the materials and processes with which they work - and permit only trained personnel to work on hazardous assignments.

5. Insure that all operations are conducted strictly in accordance with approved standing operating procedures - using constant capable supervision to police the jobs.

Always keep in mind that

"Safety responsibility is a continuing process."

A study and evaluation of hundreds of accidents convinces us that people may be critical of dangerous operations or potential hazards but not critical enough to change their unsafe habits. It seems that people have learned to live dangerously and they hope for the best without considering the deadly consequences in case of the worst.

Like we said in the beginning, the future depends to a great extent on what we do about the past. Each accident - no matter how slight or unimportant it may appear - could have resulted in a fatality if the circumstances had been a little different. All accidents must be investigated, the causes determined, and corrective action taken to prevent a similar accident. We can only prevent accidents if we will accept each accident that does occur as a lesson from which we draw benefit. This is a lesson we cannot afford to fail. Never forget that Accident Investigation is your Concern for Man.

BLAST EFFECTS FROM EXPLOSIONS (FROM MILLIGRAMS TO MEGATONS)

F. A. Loving

Eastern Laboratory, E. I. du Pont de Nemours & Company
Gibbstown, New Jersey

I would like to open our discussion of blast effects by showing you a series of slides of blast effects from explosions of various size. Slide 1 shows the explosion of approximately 3 milligrams of nitroglycerin or about 10^{-5} lbs. The device here is a microburette. The explosion occurred in the needle and you can see some fragmentation. The blast effects from such a small quantity are confined to missile damage. The quantity is too small to produce any other physical effects.

Slide 2, showing a Campbell soup can, contained the detonation of a blasting cap. Again, the principle damage from this size charge (about 10^{-3} pounds) is primarily from missiles. For persons very close, there could be blast pressure sufficient to cause some ear damage.

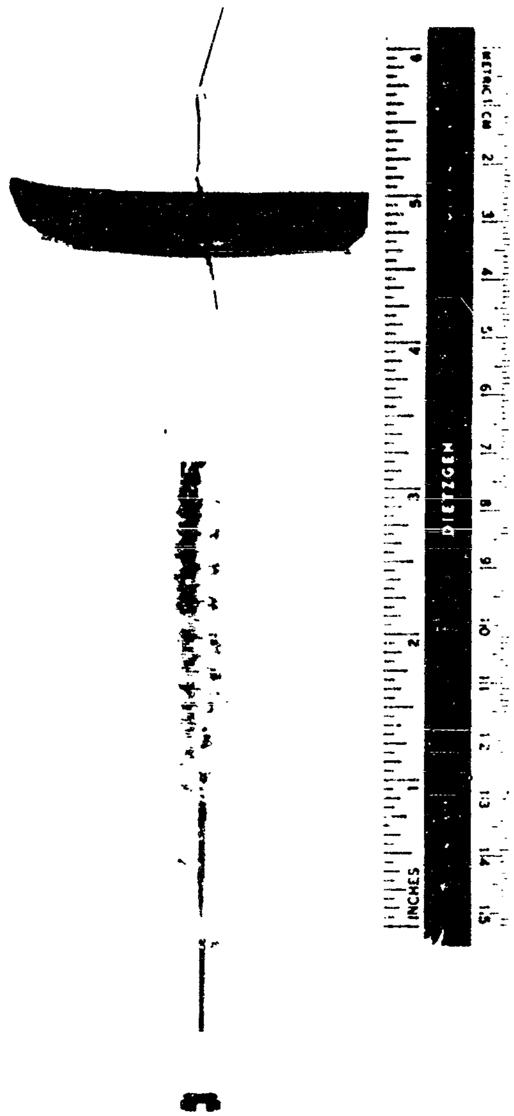
Slide 3 shows the effects of an explosion in a laboratory of 50-100 grams or about 10^{-1} pounds. The damage, you can see, is extensive. At this level, we must begin to have considerable respect for quantities of material which can detonate. This blast, in addition to doing the damage you see to the apparatus in the laboratory, had sufficient force to crack masonry walls in the building and completely remove windows.

Next, I would like to show you a blast chamber, Slide 4. This spherical barricade was designed to contain high explosive detonations for testing purposes. It was designed to withstand repeated detonations.

One is reminded of an ancient bit of doggerel, humpty dumpty sat on the wall - humpty dumpty had a great fall, and in Slide 5 we see the falling. This steel sphere, 3/4" thick - 12 ft. in diameter, was fragmented as you see by 22 pounds or about the order of 10^1 pounds of explosives.

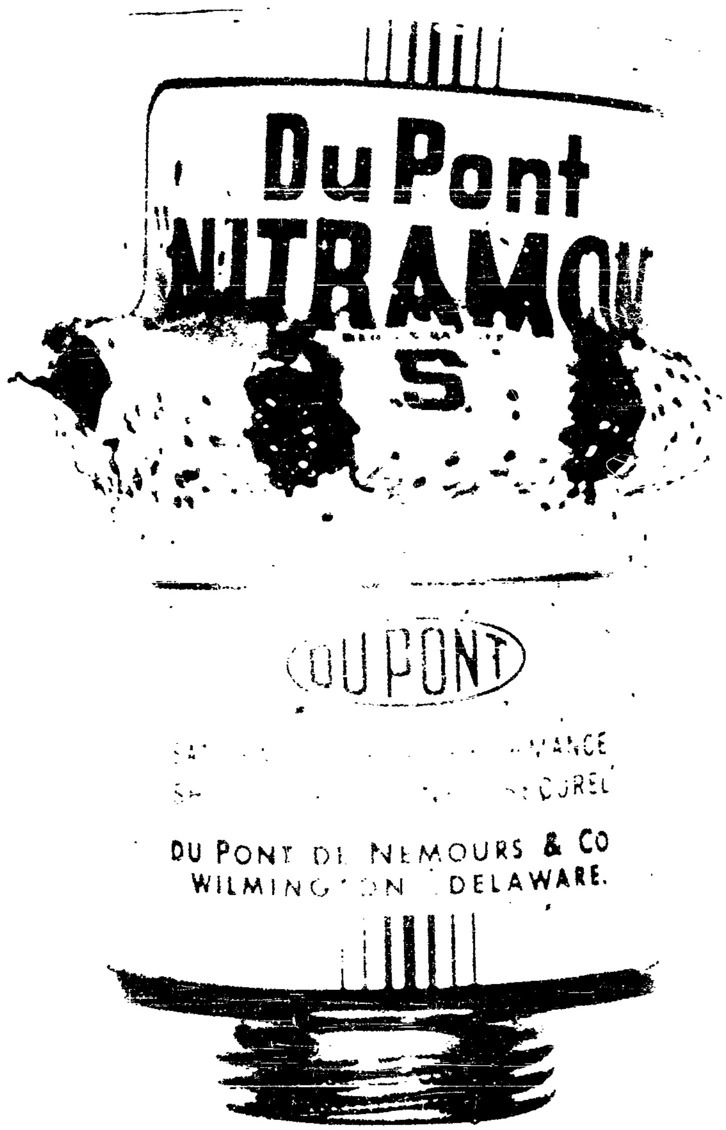
Slide 6 shows the effect on a plant building of about 10^3 pounds of high explosives. At this level, we see complete demolition and destruction of the building structure and extensive damage to heavy earthen barricades that surrounded the building. The explosion here was one that occurred some years ago on a plant producing commercial explosives.

In Slide 7 we will move to about 10^5 pounds. This snow-covered countryside shows in the center a large crater where a mixing house

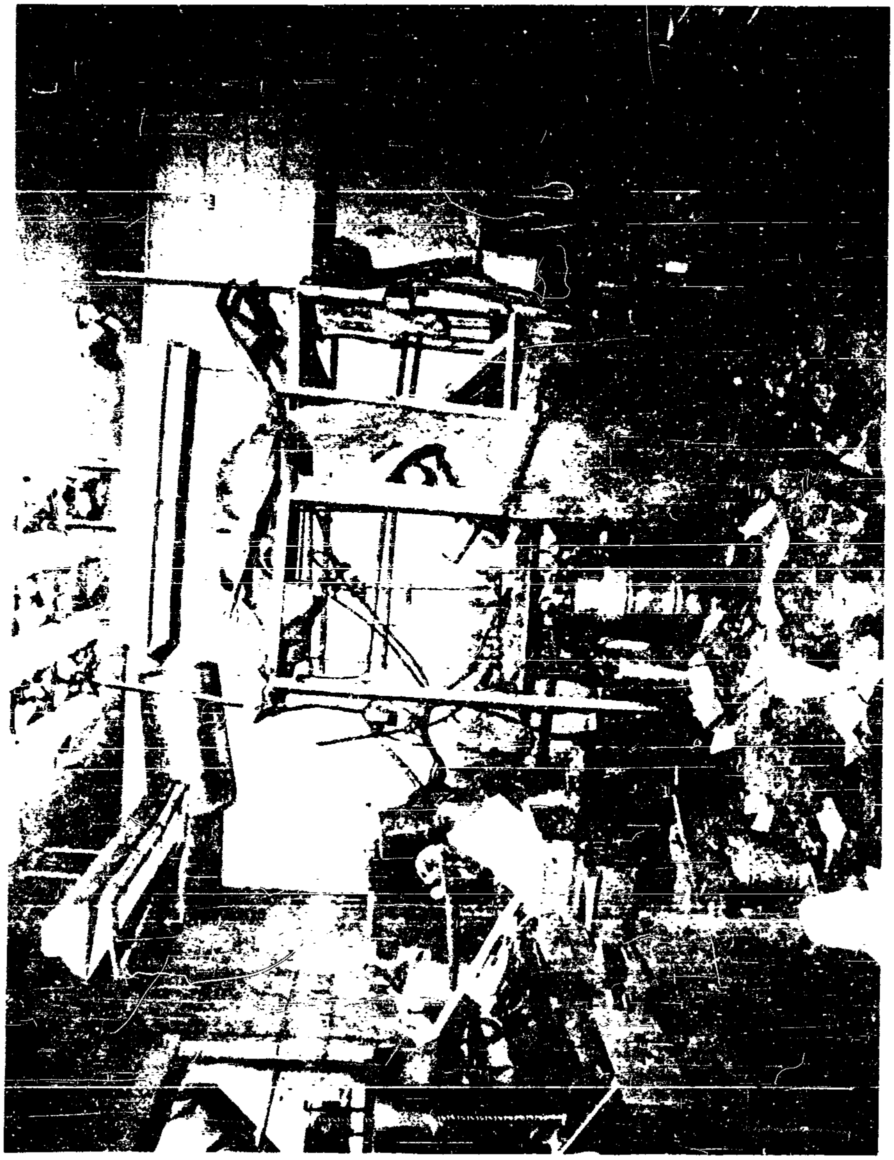


Slide 1

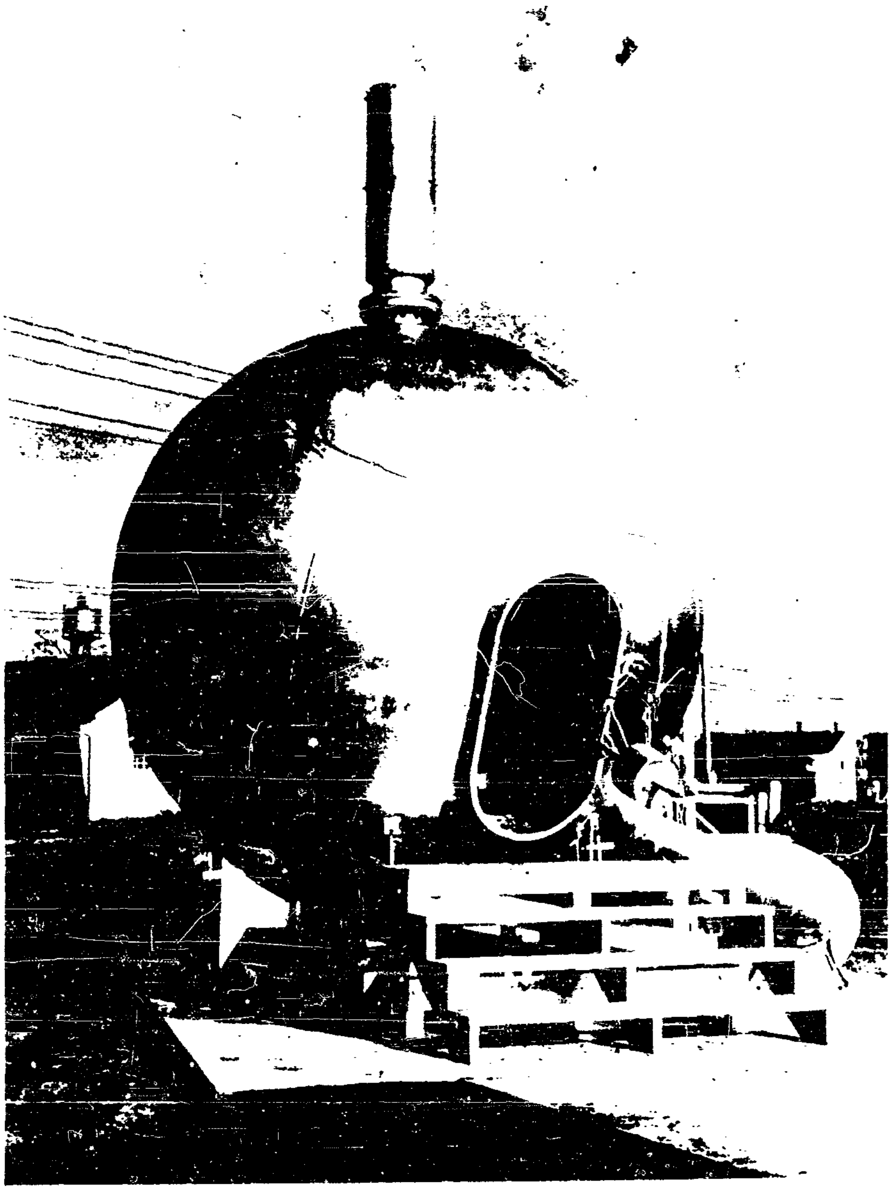
UNCLASSIFIED



Slide 2



Slide 3



Slide 4

Slide 5

Slide 6

UNCLASSIFIED

Slide 7

UNCLASSIFIED

for ammonium nitrate fuel mixtures, used for blasting, first caught fire then detonated. Several houses around this crater, were completely destroyed at distances up to five hundred feet.

Slide 8 is a picture that has been widely publicized. You may recognize it. It is one view of the effects of the Texas City explosion some years ago in which the amount of material was something of the order of 10^6 pounds. About 2 MM pounds of material exploded and as you will recall, demolished structures at considerable radius.

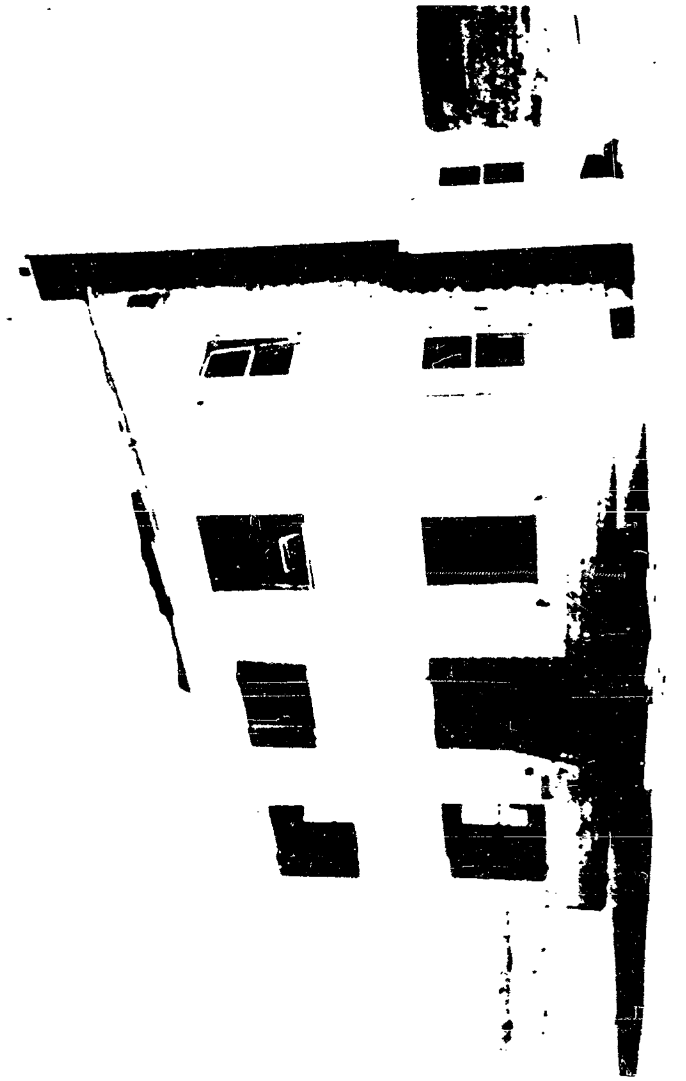
Finally, in order to justify my title, I will show you a couple of slides taken from the publication of the Atomic Energy Commission, "The Effects of Nuclear Weapons" (Ref. 3), which show a typical frame house before and after the explosion of a nuclear weapon which may have an explosive equivalent from 10^7 to 10^{11} pounds. Slide 9 shows the frame house before being struck by the blast wave, and Slide 10 shows the same frame house after being struck by the blast wave.

Now I have skipped many orders of magnitude in calling this 10^7 to 10^{11} pounds of explosive, and this brings us really to the point of the talk. And that is, that these blast effects are equivalent in many respects, regardless of their size, and the effects may be predicted with some precision by applying scaling laws. Hence, it is possible to predict blast effects and consequently to design safe hoods, barricades, safety shields, and provide protection from ear damage from blasts and missiles. A typical blast pressure wave generated by an explosion is shown in Slide 11. There is a shock wave in which the pressure increase is essentially discontinuous followed by a nearly exponential decay. This sketch represents side-on pressure. It is the free field pressure in the blast wave and takes into account none of the phenomena which occur when the blast wave collides with an object.

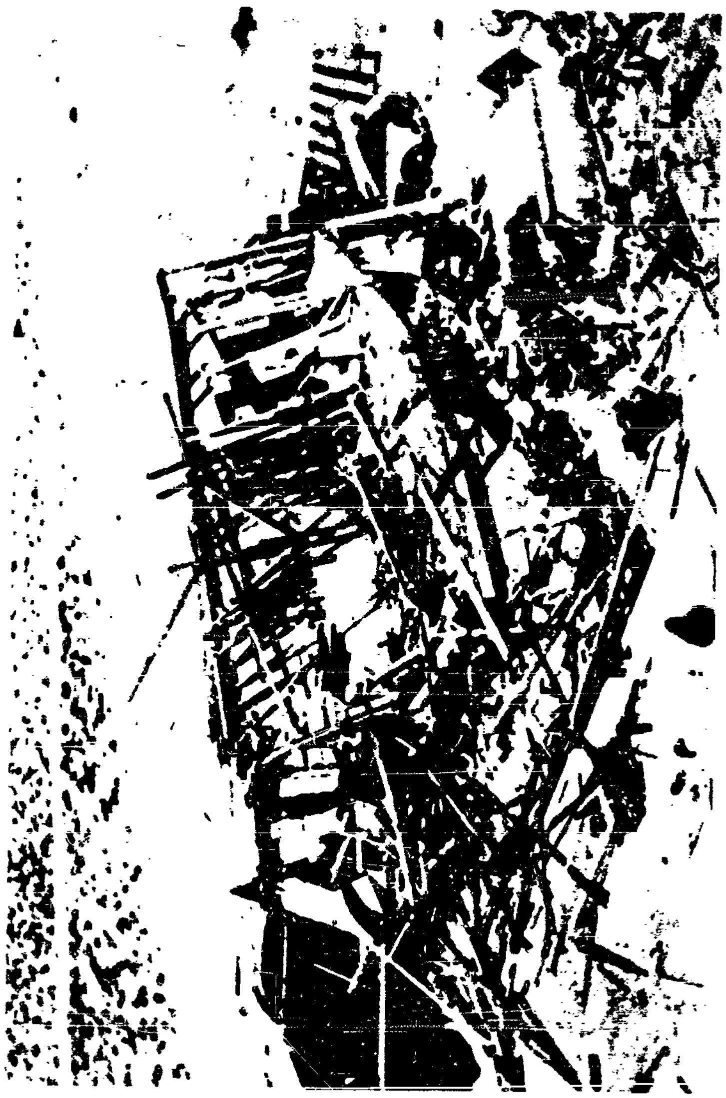
When collision with an object occurs, there are changes in the pressure pattern which are shown in the next slide, Slide 12. An elevated peak pressure due to the collision process of the blast wave with the object is followed by decay that is also at a higher level because of so-called dynamic pressure. There is pressure due to the particle velocity or wind behind the shock front which impinges upon the object being struck contributing to the force applied. Finally, a decay to ambient pressure is followed by a rarefaction wave. This is the type of blast wave we usually encounter in safety considerations for accidental explosions in plants and laboratories because, of course, the shock wave must hit something before any damage is done.

Well, what can we do about it? Scaling laws are illustrated in Slide 13. These scaling laws have been known for a long time and have been corroborated in measurements all the way from very tiny explosions on the laboratory scale right up to the largest megaton

Slide 8

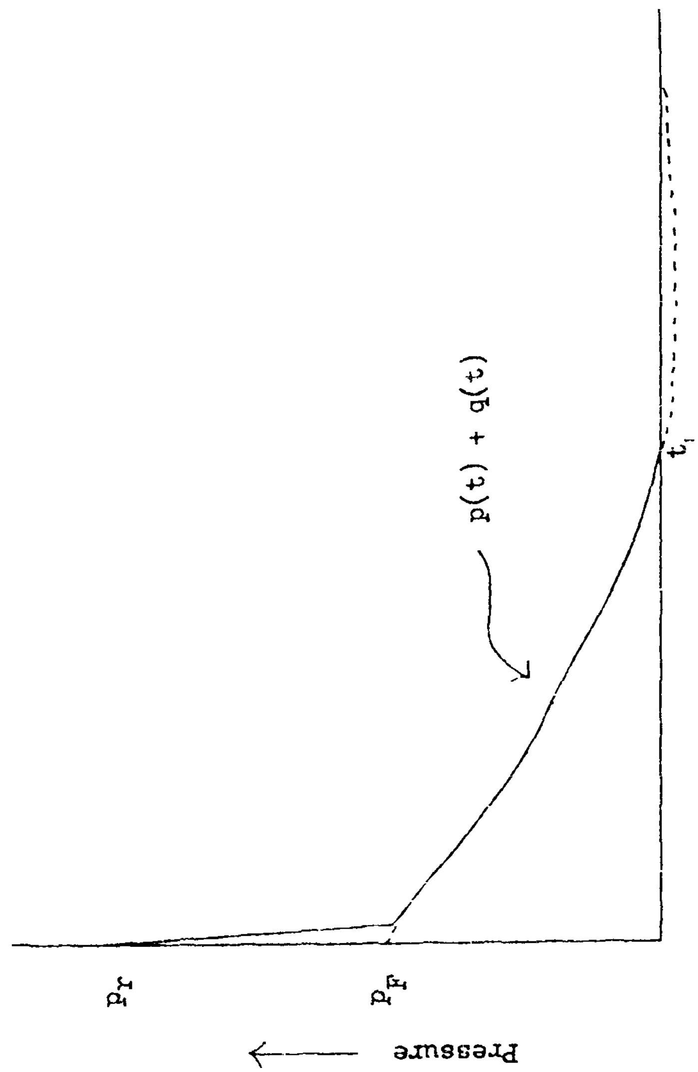


Slide 9



Slide 10

Figure A-2



Slide 11

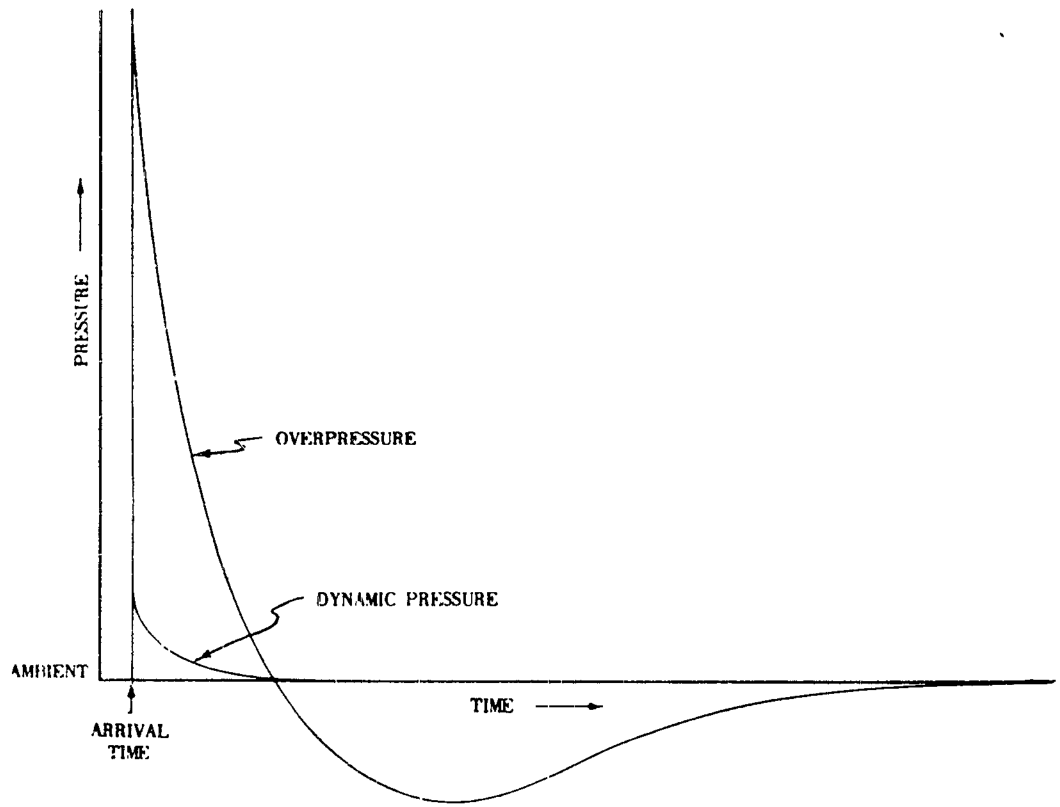


Figure 3.12. Variation of overpressure and dynamic pressure with time at a fixed location.

Slide 12

$$D = D_o \times W^{1/3}$$

$$t = t_o \times W^{1/3} \quad \text{at } D = D_o \times W^{1/3}$$

$$I = I_o \times W^{1/3} \quad \text{at } D = D_o \times W^{1/3}$$

Slide 13

weapons that have been tested. The scaling laws shown are for pressure, impulse and time duration of the blast wave. The appropriate scaling factors are distance, D, and the cube root of charge weight, $W^{1/3}$.

The scaling laws can perhaps be grasped more clearly by looking at curves of blast parameters. These are plots of experimental data of Hoffman and Mills (Ref. 1).

The first, Slide 14, shows peak pressure vs scaled distance, $R/W^{1/3}$. Side-on pressure is the free field blast pressure. Face-on pressure is a measured pressure when the blast wave has collided at normal instance with a surface.

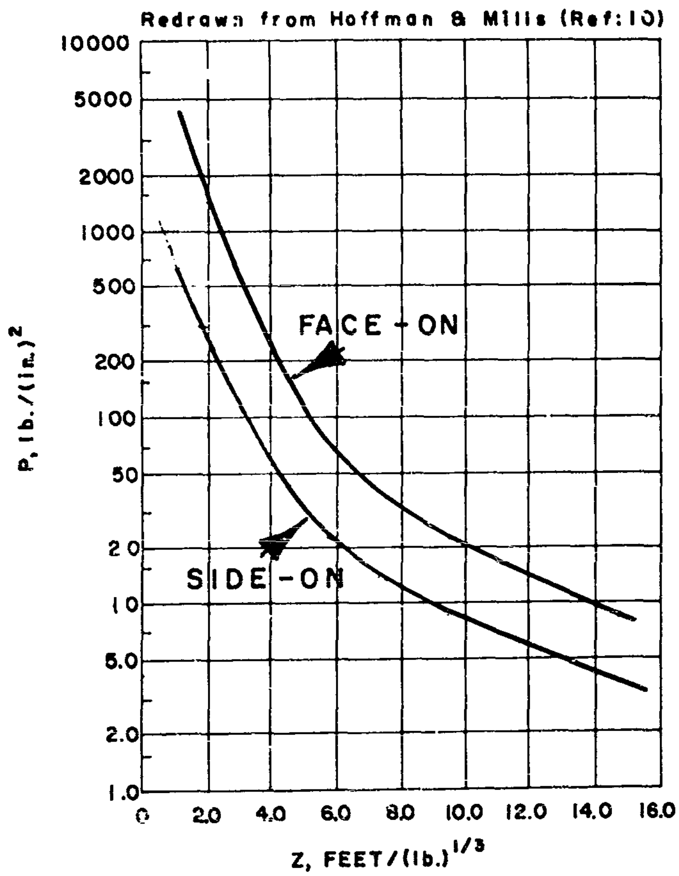
Similarly, we have next, Slide 15, a curve of the duration of the blast wave. Again, we have scaled distance plotted now against not time but scaled time. So it is necessary to determine the scaled distance, read a scaled time, multiply this by $W^{1/3}$ to get the blast wave duration.

Finally impulse is shown for the side-on and for the face-on blast wave, Slide 16. The final step then is to use these blast parameters in order to compute or estimate the effects on people and things - well, first things. In order to compute the response of a structure to a blast wave, two simplifications have been used by Newmark and others. The first is, to approximate the blast wave by a triangle - shown on Slide 17, where the peak pressure we are now calling force (peak pressure times the area being struck) and the time is the duration of the blast wave. When the force time history of the blast wave is represented as a simple triangle, there are some simple mathematics that will permit us to compute the response of the structure. The other thing required to make the calculation is to know the response of the structure - in other words, how it deforms with a given force.

This can be obtained from a force-deflection curve such as shown here, Slide 18. This will be recognized as a stress-strain curve in which, in the elastic range, the deflection of the structure is proportional to the applied force. Beyond the yield point, there are simplified curves for ductile plastic flow and for brittle fracture. Given this model for structural response and a triangular force-time curve for the blast wave, we can calculate the response of the structure to the blast wave collision. In most laboratory and plant design problems, one may neglect deformation in the plastic range. In other words, we don't want the yield point exceeded. If that is the case, a simplified Newmark equation may be used. More complete calculations including estimates of plastic deformation are discussed in References (2), (3), and (4). First, large T is the natural period of the structure, M_e is the mass, and K_1 is the slope of our force deflection curve shown in the last slide, Slide 19. Small t is the duration of the blast wave and Q_e and F are, respectively, a force equal to the peak pressure in

Figure 2

FACE-ON AND SIDE-ON PEAK PRESSURE
vs.
SCALED DISTANCE



Slide 14

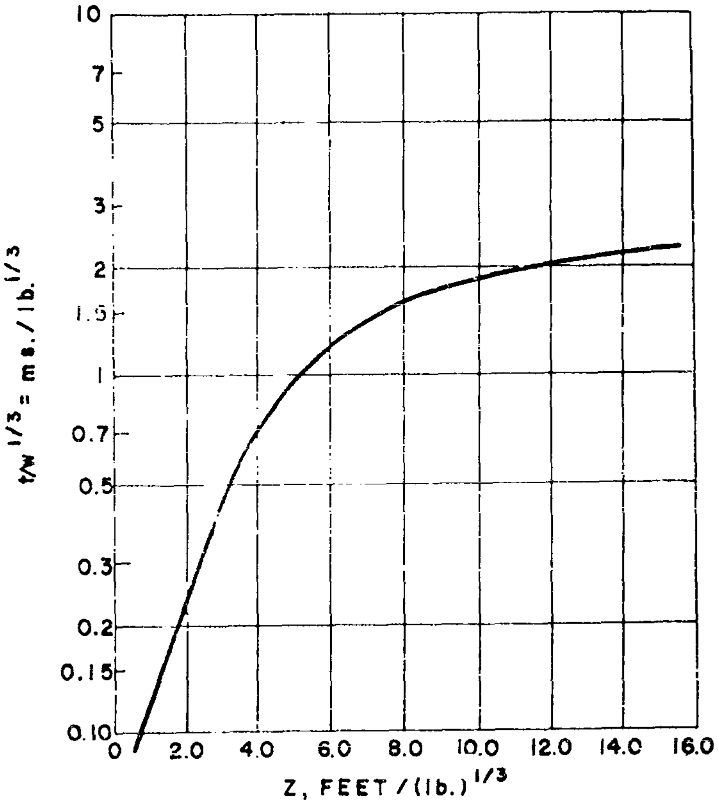
Figure 4

FACE-ON AND SIDE-ON SCALED DURATION

vs.

SCALED DISTANCE

Redrawn from Hoffman & Mills (Ref. 10)



Slide 15

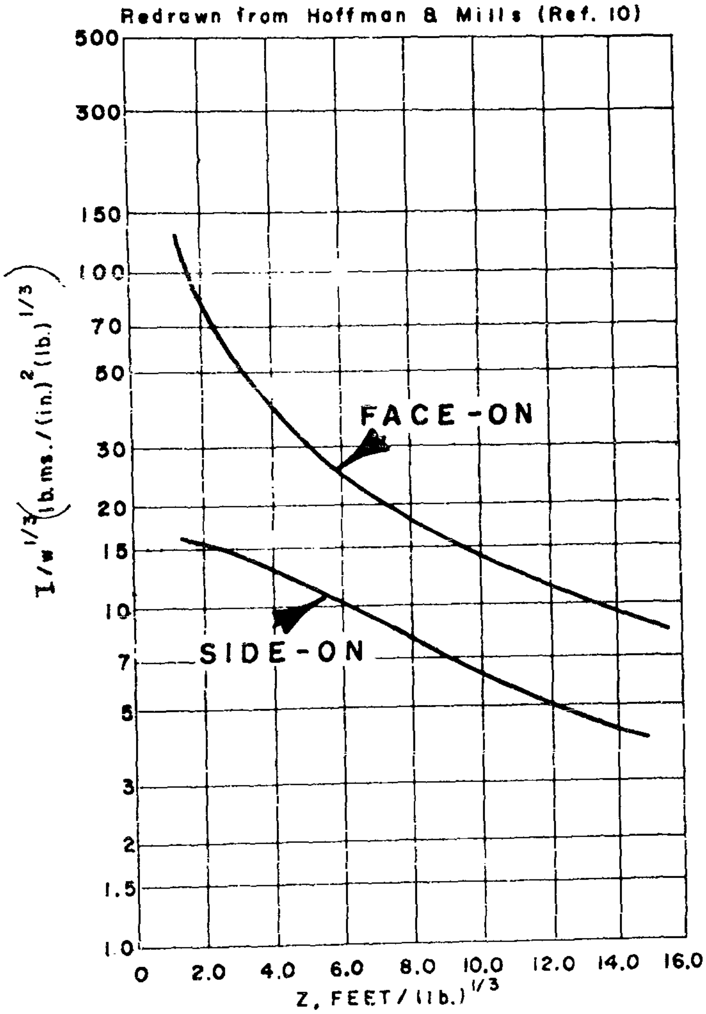
Figure 3

FACE-ON AND SIDE-ON SCALED IMPULSE

vs.

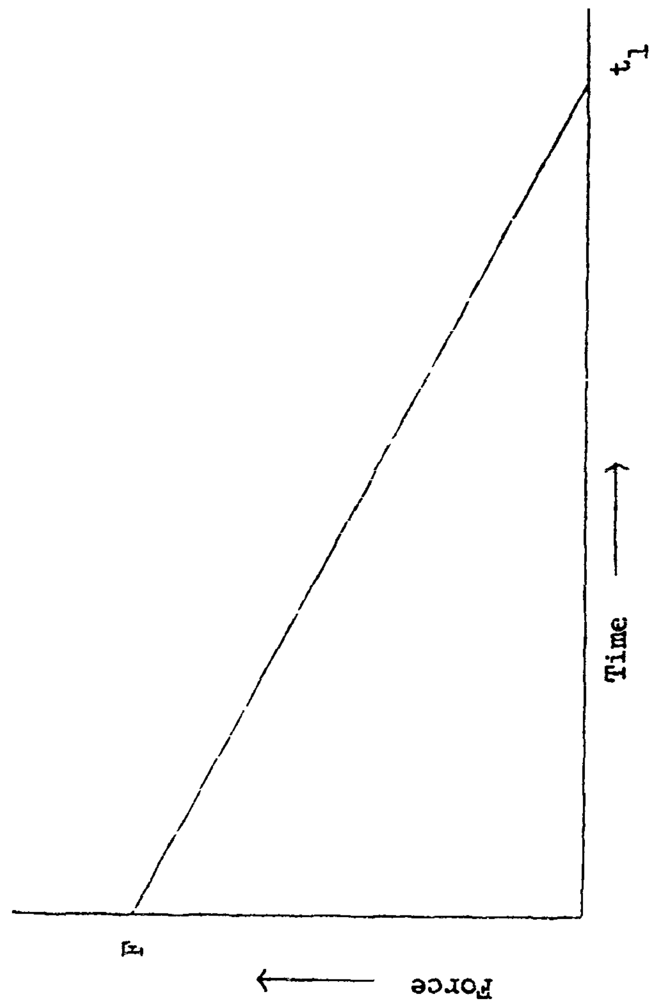
SCALED DISTANCE

Redrawn from Hoffman & Mills (Ref. 10)



Slide 16

Figure A-1



Slide 17

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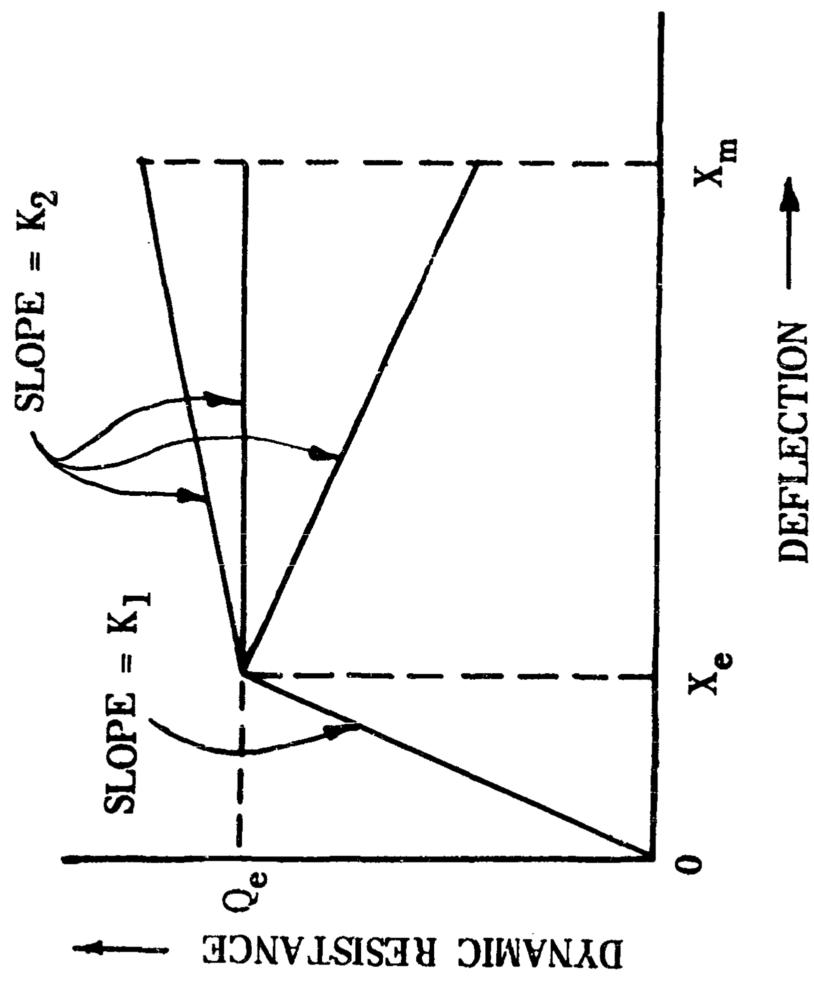

Figure 6.99. Idealized dynamic resistance-deflection curves.

Slide 18

$$\frac{F}{Q_e} = \frac{T}{\pi t_1} + \frac{1}{2\left(1 + 0.7\,\frac{T}{t_1}\right)} \qquad (2)$$

$$T = 2\pi\sqrt{\frac{M_e}{K_1 g}} \qquad (3)$$

Slide 19

our triangular blast wave times the area on which it is pushing, and a force which the structure will withstand at a given deflection, say at the yield point. It is then necessary to iterate for a given structure the appropriate weight of explosive and distance that will satisfy the F/Q_e ratio defined. It is interesting to note that for very large periods and very short durations of blast collision, the fraction becomes a large number. Hence a massive wall will withstand a very high pressure if applied only a short time. For an exceedingly long blast wave, together with a very short period the ratio of these two forces becomes one-half. This corresponds to an instantaneously applied static pressure which will deform the wall just twice the deformation of a very gradually applied static pressure.

These equations permit us to estimate the response of structures. Now, how about the response of people? The chief hazard to personnel from explosions is missiles and this is beyond the scope of the present paper. A substantial mass of material between personnel and the missile generating device is required and the only trustworthy way to assess missile damage is to test a mock-up of the device in question. As far as ear damage is concerned, at our Laboratory we have reviewed the literature references and have decided that permanent ear damage is unlikely at peak blast pressures below 1 pound per square inch. The attenuation of walls, blast chambers, and the like can be taken into account, and the use of ear muffs has been shown to reduce peak blast pressure by about a factor of 10. Thus with a good set of ear muffs, a man could withstand safely a blast pressure of up to 10 pounds per square inch without ear damage. A solid wall with no large openings to allow blast wave to emerge from a blast chamber will usually attenuate the pressure by an additional factor of 10 and [illegible] simple intervening walls with open ends so that the shock wave must diffract around a corner turning its direction at least 90° can be counted on to attenuate blast pressures by about a factor of 5 over the blast pressure of a direct path.

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Mr. Saffian: I have two questions. First, along the lines of your earlier discussion, wouldn't you say that the pressure that a human body can withstand is also a function of the time duration?

Mr. Loving: Yes, it is to a degree, certainly. One reason we limit, we are again a little bit happy with our 10 PSI limit at the man. If he has ear protection on and the if the peak pressure does not exceed 10 PSI, we think he's quite safe from internal damage, furthermore, if we permit even with more ear protection or better ear protection or if you were willing to push this allowable limit higher, you arrive at the point in here somewhere, particularly for a long duration, where the man can't keep his feet. Even tho he is protected from missiles, he may become a missile himself. And this is definitely a function of the duration as well as the peak pressure of the blast.

Mr. Saffian: Another question. I got the impression from the charts and references that you presented that the assumption is being made throughout all this that the walls in question are being subjected essentially to a uniform or plane wave blast loading such as might be expected at reduced distances of maybe 3 and above. Is that so?

Mr. Loving: That's correct. It depends of course, the curvature of the blast is significant and we have used this calculation really just to make an engineering estimate. Usually the set-up is so complicated that you can't define all these deflections and pressures to the third decimal point. It has been useful, however, in estimating deflection. What we have done, say in the case of a wall that is fairly close to an explosive, perhaps a rocket test stand, is we have assumed for a flat reinforced concrete wall that the area struck by the blast wave is a circle whose radius is about equal to the distance to the charge. Beyond that point the angle of collision becomes oblique and the forces are substantially reduced. It's partly a matter of horse sense, if this charge blows a hole in the wall, it's close enough, you're pretty sure it's going to blow a hole in it, it's not going to blow the whole wall over. On the other hand, you can examine the case for blowing the whole wall over, you simply have to form an engineering estimate of force deflection in another mold.

Mr. Saffian: Thank you.

Mr. Endsley: In the criteria for ear damage, is this on a constant exposure or is it an unplanned noise?

Mr. Loving: Unplanned definitely. By no means would I recommend continued exposures to 1 PSI blast pressures. I'm pretty sure that in long exposures, damage would occur. This is strictly a one shot affair, it's a mighty loud noise, 160 or 70 db or so. Fortunately one can stand 170 db in a single shock wave a lot easier than one can stand continuous noise of 170 db, for those of you who are interested in rocket noises.

Mr. Scott: If in your sphere example you have a rapidly deflagrating agent rather than a detonating agent and the phenomenon is one of a pressure rupture rather than a detonation, do you then arrive or estimate the consequences in the same manner and if you do, how do you equate the pressure rupture phenomenon to a given amount of detonating material?

Mr. Loving: This is one we are asked often and the answer is no, you cannot use this approach. The reason is that you could use a similar set of differential equations if you could define the pressure time history and in almost every case we cannot. In the case of a deflagration, the forces are less severe and in the case of a deflagration the presence of vents are of considerable help in relieving the structure. In the case of a detonation where the shock wave impinges, vents do us very little good and the answer is unless you can define the rate of the reaction with considerable precision, you have trouble. And what we have done in the detonation case is the more severe. Consequently if we design for that, we feel we're okay for deflagration, but for deflagration type reactions, it's - unless you can define the rate with some precision, this method will not apply.

Mr. McElroy: In discussing the explosion in the hypodermic needle, you made reference to a critical diameter, would you amplify on that a little bit please.

Mr. Loving: In the history of explosive testing, it turned out that it was possible in many cases to define a critical diameter, a diameter below which the detonation would not propagate in a column. This is sometimes made use of for safety purposes. It is a very unreliable number, it's a function of the environment, chiefly of the confinement and not of the diameter. One can take paper soda straws and prove that the critical diameter for nitroglycerin is 1/8". This nitroglycerin detonated continuously and had a fairly high velocity in a few mils diameter, so the caution is "do not rely on critical diameter unless you have very carefully tested in exactly the environment that you propose to use it."

Mr. Paul King: In your discussion of your one pound criteria, is that face-on or side-on pressure and is the face-on pressure for the man about two times the side-on pressure. Could you discuss that?

Mr. Loving: Yes, I'm sure the effect on ears is a function of the direction in which the shock wave approaches and if a man has the side of his head and ear pointed towards the explosion he will sustain higher chance of ear damage than if his face is directly towards it. We think we are in good shape here by again having taken this very conservative 1 PSI allowable limit.

Mr. King: Would that be side-on pressure as measured by a gage?

Mr. Loving: Yes, we have used side-on pressure in the case of that design.

Mr. Zihlman: What kind of over-pressurization do you think is necessary to cause a fatality?

Mr. Loving: There is a recent publication covering the experience chiefly in England during the war, I don't have the exact reference, and as you might expect, there is a very large scattering in this. People as I recall were reported to have withstood some 400 or 500 PSI, on the other hand, there are cases where internal bleeding and damage to internal organs has occurred as low as 40 or 50 and if any of you can correct my precise numbers, I'd appreciate it. But it's highly variable and also a man who is in a position where he is struck with a blast pressure of anything like hundreds of PSI is almost invariably severely damaged by either being struck by missiles or by himself becoming a missile and traveling and hitting something. You almost always fail to supply that and it's difficult to find with precision what these internal affects are.

STUDIES OF SENSITIVITY AND STRENGTH OF REACTION IN MATERIALS PRODUCING LOW IMPULSE

by
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The standardized gap test is designed to measure the shock sensitivity of materials reacting to give a high impulse; the minimum impulse for the reactions it tests is that necessary to punch a hole in the cold-rolled steel witness plate (1). All non-porous propellants which have been tested have either produced much more than this minimum impulse or so little that the witness plate was undamaged. However, some porous charges have exhibited no-go at zero gap i.e., failed to punch the plate, but have also shown a shock initiated reaction of sufficient impulse to bulge and bend the witness plate. Any reaction capable of damaging a 3/8" thick steel plate is of importance for safety considerations even if the damage it can cause is less than that of the higher impulse reactions. It is, therefore, desirable to have a means of assessing such lower impulse reactions.

In principle, it is possible to design separate tests to measure: (a) sensitivity of initiation to any self-propagating reaction, and (b) the strength i.e., maximum pressure of the self-propagating reaction initiated by shock. In practice, such an absolute division in testing non-porous propellants seems unnecessary because no sample tested has been in the lower impulse region; the division seems undesirable because of the long time required to develop new reliable tests. Consequently, the standardized gap test will be used, as in the past, to cover simultaneously parts of (a) and (b) and if a material is found to damage, but not punch, the witness plate, information will be obtained to supplement the gap test result.

The simplest way to obtain such supplementary information is to use the standardized test geometry with the replacement of the 3/8" witness plate by another sensor capable of responding unambiguously to lower impulse loadings. The first substitute investigated was thinner witness plates. It was found that they gave too small a range in response and were too variable from lot to lot to be satisfactory. Such variation does not affect previously reported results for high impulse reactions because the plate loading is so much greater than that required to punch a hole.

The method which was then developed, and which is satisfactory, utilizes an explosive witness system. Fig. 1 shows the standardized gap test with a steel witness plate. To study lower impulse reactions i.e., those that result in pressures of about 55 kbar or less in the reacting material, the steel plate adjacent to the test material is replaced by another 5.5" length tube of any detonable material for which the initiating pressure is already known; the modified geometry is shown in Fig. 2. As the figure shows, the steel plate is still used to witness the high impulse reaction of the explosive witness after the high impulse reaction has been initiated by the low impulse reaction of the test material.

The choice of explosive sensors can be made from materials already studied. A typical selection is:

Explosive witness	Initiating Pressure (kbar)
Propellants	ca 50
TNT (cast)	37.3
Comp B (cast)	21.2
DINA (cast)	6.3

Intermediate levels can be obtained by combining or diluting these materials. Since all of them are non-porous and have approximately the same impedance as the non-porous propellants, the incident pressure, or pressure generated by the reaction of the test material and the quantity of interest in assessing damage, will be nearly equal to the initiating pressure required by the explosive witness. Porous sensors e.g., PETN at ρ_0 = 1 g/cc with 2.5 kbar initiating pressure (2), should be avoided because the incident pressure from a non-porous test material must be much higher than the low initiating pressure of a porous acceptor to induce its detonation. Similar difficulties from impedance mismatch arise in testing a porous charge with a non-porous explosive witness. The study of low impulse materials by the method indicated in Fig. 2 is best applied only to non-porous materials.

The present method not only provides an estimate of reaction pressure of the test material but also, if the strength of the reaction warrants it, a way of measuring the shock sensitivity of the reaction. This can be done by using the standard gap testing procedure with the appropriate explosive witness system in place of the steel witness plate. Thus a measure of both the ease of initiation and of the strength of a low impulse reaction can be obtained.

Although the method is designed to study non-porous materials, it is necessary to illustrate its application with a porous charge because no non-porous propellant exhibiting the lower impulse behavior is available. Ammonium perchlorate (AP) of average particle size of 25μ and loading density of 0.85 g/cc was chosen; the test results are given in Table 1.

First, the initiating pressures of cast TNT and cast Comp. B, the materials to be used in explosive witness systems, were determined to be about 37 and 23 kbar respectively. It was also shown that doubling the length of the Comp. B acceptor had no effect on the measured initiating pressure i.e., that the length/diameter ratio of the standard gap test is sufficient for complete build-up. Earlier results on a porous charge of AP were repeated: a no-go at zero gap in the standardized test but obvious damage to the witness plate. With both of the explosive witness systems, a go was obtained and in both cases the required incident pressure was about 15 kbar. To determine the pressure required to initiate the AP it is necessary to use a Hugoniot for this material. Of the available Hugoniot data, that set which might best approximate a porous charge of AP is the Hugoniot for pressed PETN (ρ_0 = 1 g/cc) (2). Use of this Hugoniot and an incident pressure of 15 kbar at the Lucite/AP boundary gives an initiating pressure of about 5 kbar for the AP. This material is therefore very shock sensitive and its low impulse reaction easy to initiate.

The maximum pressure generated by the low impulse reaction is harder to estimate since it requires Hugoniot data for the reaction products. Qualitatively, it is more than sufficient to initiate TNT, the less sensitive explosive, but not much more than sufficient since an attenuation of about 0.22" of Lucite prevents the initiation. The computed density of the detonation products for AP (ρ_0 = 0.85) is about 1.16 g/cm^3 (3). Since Lucite has a density of 1.18 g/cm^3, it is reasonable to assume a sufficiently good impedance match between the AP products and Lucite to make the pressure transmitted equal to the incident pressure exerted by the detonation products. This pressure is then that in the Lucite at zero gap. Without running a complete calibration curve for the AP (ρ_0 = 0.85) loading of Lucite, its maximum pressure can be estimated from the two points* on this calibration curve given by Comp. B and TNT used as explosive witnesses. The curve, log (pressure) vs. gap thickness, can be expected to be linear, as was that for tetryl (1), and extrapolation of the linear curve to zero gap gives a pressure of 33 kbar. For such an approximate treatment, the value of 33 kbar is in good agreement with the theoretically computed value of 25 kbar (3). Hence a 25 kbar loading of the 0.215 in. gap of Lucite by the AP detonation products is a reasonable one to result in the transmission of about 37 kbar to the TNT witness and thus initiate its detonation.

Finally, the test data in Table 1 for the length of gap between the acceptor and explosive witness, necessary to attenuate the loading from the AP reaction until it is too weak to initiate the explosive witness, serves also to show that the initiation of the explosive witness is by shock, not by a flame front from the decomposing AP. The plastic material of the gap will transmit compression pulses, but prevent propagation of any normal burning front.

*These two points were not completely defined (see Table 1). For this estimate, the mid-range values of 125 cards (Comp. B) and 21.5 cards (TNT) were used.

TABLE I

Study of Low Impulse Reactions

Material	Density g/cc	Temperature* °C	Witness System	50% Gap No. Cards	Init. Pressure, kbar	Comments
TNT(c)	1.613	6.7 to 10.6	Steel Plate	141 ± 1	36.7	
Comp B(c)	1.697	12.2	" "	195 ± 1	23.2	Same value within difference to be expected for temperature difference.
Comp B(c)	1.697	7.0 to 8.0	Comp B(c)	185≤N≤188	24.5	
AP**	ca.0.85	20.6	Steel Plate	N≤0	?	Plate deformed by large hump.
AP	"	23.9	Comp B(c)	212<N<225	ca. 5	See text. Gap value same within difference to be expected for temperature difference.
AP	"	13.4 to 14.3	TNT(c)	207	ca. 5	
			Gap Placed between Acceptor and Witness System (Zero gap between donor and acceptor)			
AP	ca.0.85	24 to 25	Comp B(c)	100<N<150		Reaction of AP gives impulse more than sufficient to initiate cast TNT, and therefore much more than sufficient to initiate Comp B. Excess of impulse over that to initiate TNT is small.
AP	"	12.8 to 14.4	TNT(c)	18<N<25		

*Temperature conditioning facilities were not available at time of this work.
**The ammonium perchlorate used was micromilled to an average particle size of 25 .

The explosive witness test has been recommended as best suited for studying non-porous charges; it can, of course, be used with any test material for which Hugoniot data are available. Because such data for the test materials are generally unknown, the test is best used so that the rating obtained from the known incident pressures is the same rating that would be given by the transmitted (initiating) pressures. This condition is satisfied only if all the test materials have approximately the same shock impedance. Thus it is possible to rate a series of non-porous propellants of about the same impedance or a series of low bulk density, granular propellants of about the same impedance. But it is not possible to obtain a quantitative comparison between a non-porous, high bulk density and a porous, low bulk density propellant without Hugoniot data for both materials. For example, the incident 50% point pressure for the boundary Lucite/cast TNT is 31.3 kbar and the transmitted pressure is 37.3 kbar, an increase of about 20%. In contrast to this, the incident 50% point pressure for Lucite/AP(ρ_0 = 0.85) is 15 kbar, the transmitted pressure is 5 kbar, a decrease of about 67%. The shock sensitivities of cast TNT and pressed AP are determined by the respective initiating pressures of 37.3 and 5 kbar, not by the required incident pressures of 31.3 and 15 kbar. Similar considerations of the impedance matching of the reaction products to the explosive witness must be made when the explosive witness procedure is used to estimate maximum pressure of the reaction products.

IMPORTANT RESULTS OF STUDY

The more important results of the present study can be briefly summarized as follows:

1. Shock initiated reactions of such low impulse that they damage but do not punch the standard witness plate can be studied by use of a high explosive system as a witness.

2. Judicious choices of explosive witnesses permit not only the measurement of the shock sensitivity but also of the maximum pressure generated by the low impulse reaction. The latter quantity gives an estimate of the damage to be expected from the reaction.

ACKNOWLEDGEMENT

The writers would like to thank G. E. Roberson and A. R. Clairmont Jr. for assistance in the firings.

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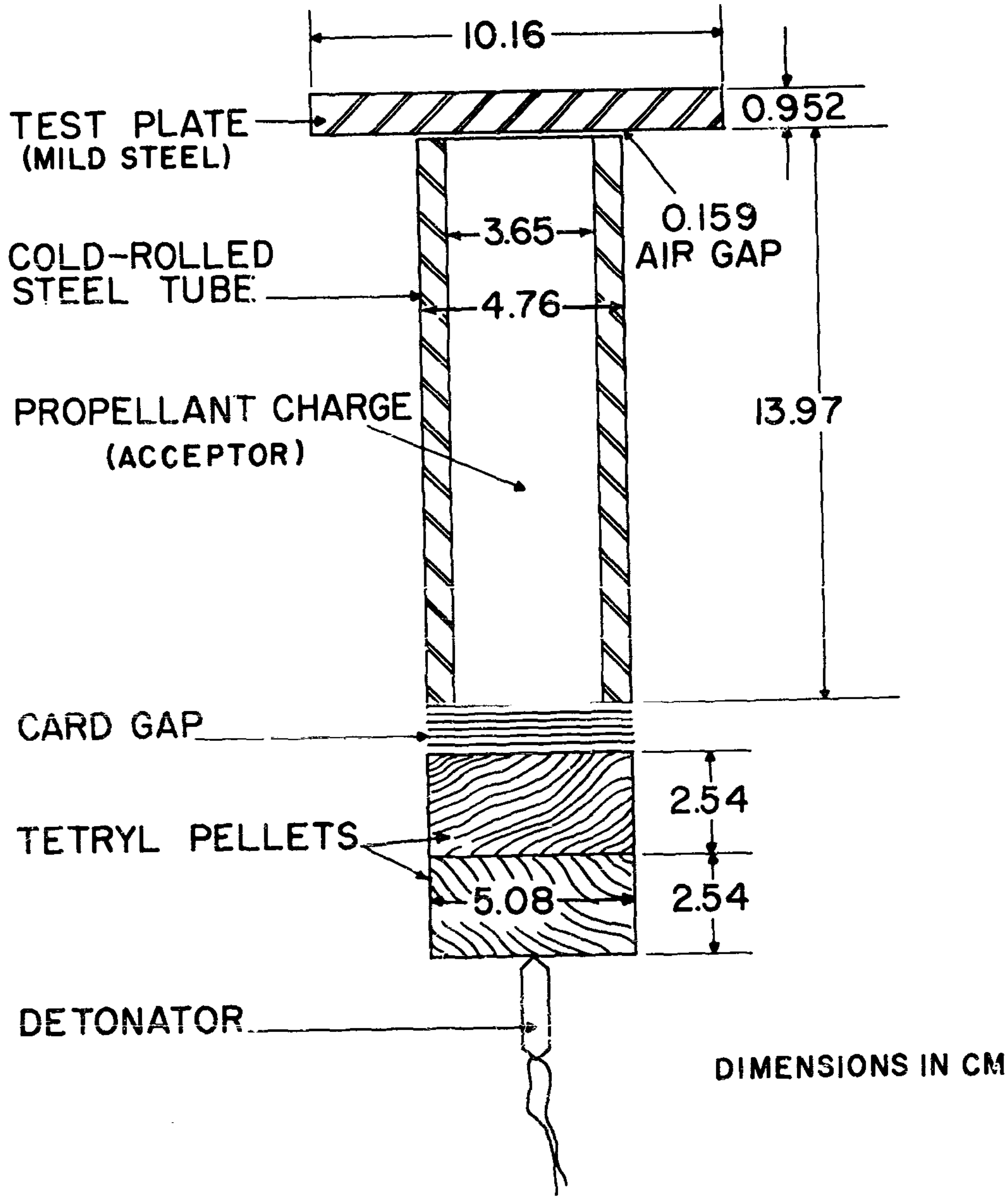
Legends for Figures

Fig. 1 Charge Assembly and Dimensions for NOL Standardized Gap Test

Fig. 2 Test Assembly Using the Explosive Witness System

Note to Printer: Please make reduction of figures by same amount so that relative proportions between the two illustrations will be unchanged.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AIR GAP
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COLD-ROLLED
STEEL TUBE
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PROPELLANT CHARGE
(ACCEPTOR)
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CARD GAP
2.54
TETRYL PELLETS
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DETONATOR
DIMENSIONS IN CM

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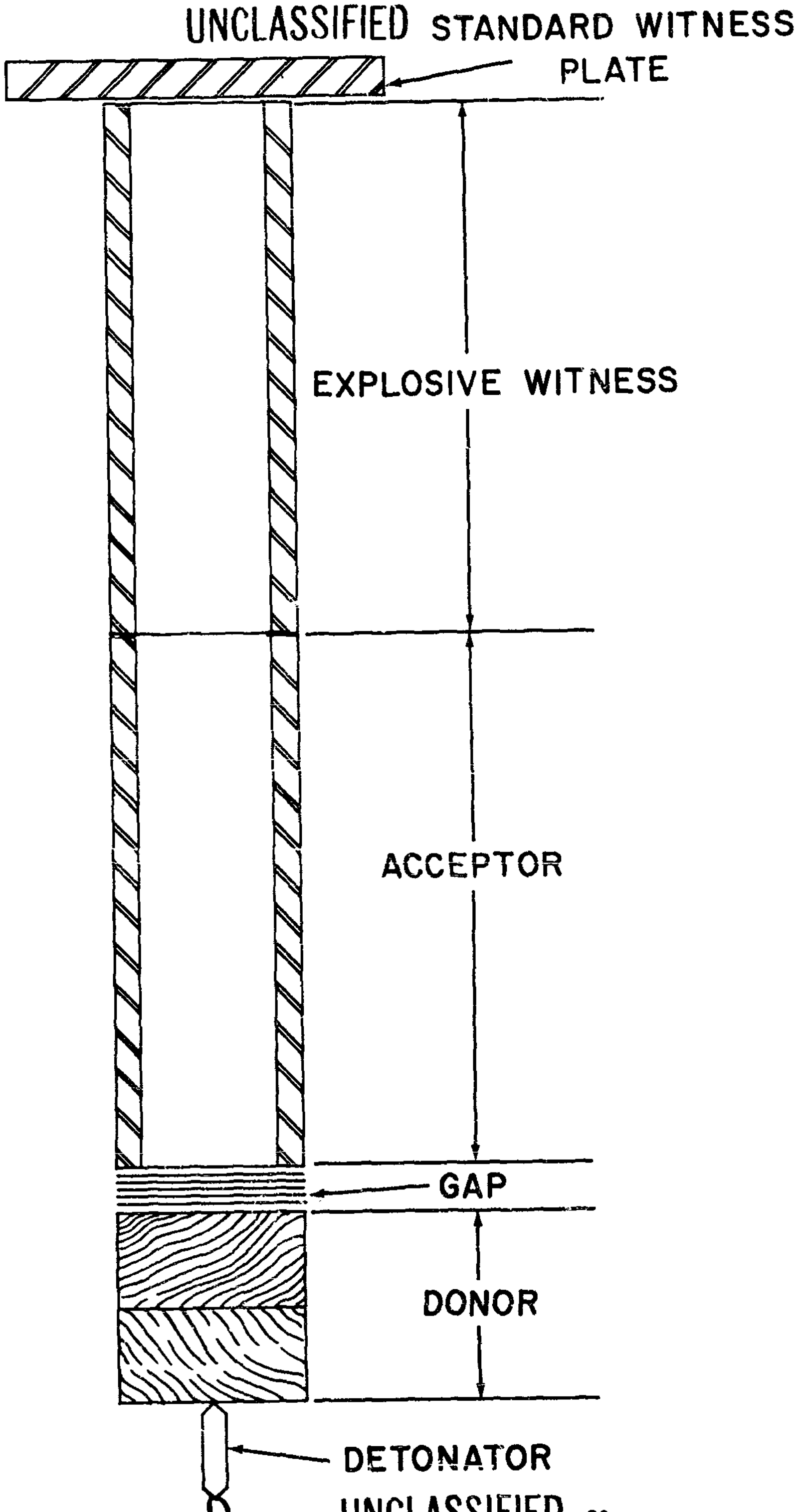

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Mr. Weintraub: I noticed that your tests were conducted with a specific L/D ratio for the acceptor. What is the variation in this test when you change the L/D and in addition, what if the diameter keeps going up? Let's assume we're now talking about 2, 3, 4, 5 and 6 ft. diameter.

Dr. Price: Yes, well I will refer you in part to some of the publications. I would say as far as the L/D of the acceptor is concerned, we're already beyond the 3, it is normally considered sufficient. We have a slight excess over that on the acceptor. Also if you recall we got the same results using a Comp. B, two lengths of Comp. B, which amounted to 11" instead of $5\frac{1}{2}$" in this particular set-up. The question on the diameter effect is far more difficult to answer. It is my opinion now from the results of the work we have been able to do that this will vary with the sensitivity of the material and within the ranges of material giving a "go" in this test, we seem to be very close to the infinite diameter value as indicated by things such as the wedge test and some of the large field tests.

Mr. John Miller: Has any test been run on ammonium nitrate or ammonium nitrate propellants?

Dr. Price: We have run some tests on highly compacted ammonium nitrate. These were no-gos on this test. We have also run some tests on high ammonium nitrate type blasting materials which gave a go on the standard test. I can't answer the question on the ammonium nitrate propellants, I shouldn't expect vast differences from some of the other propellants that we've run but I don't recall having run one.

Unidentified: Could you give us a list of your publications or associated publications so that they may be entered on the minutes of the meeting please.

Dr. Price: Yes, but I can't give them to you from the podium, I'll be glad to supply them.

Col. Hamilton: We'll be glad to publish them with the minutes of the meeting.

Mr. King: I'm not familiar with the early dates of these tests, could you tell me if anyone has made any comparison of the witness plate results with the standard Trauzel or lead block tests, and the second question, do you attempt to measure detonation velocities in the witness explosive?

Dr. Price: In answer to the first question, so far as I know, comparisons have not been made, but I believe that the lead block test anyway was not generally used as a measure of sensitivity. In answer to your second question - we have not in this particular set-up, we have in very similar set-ups, we have also the advantage of a group also at NOL working on very closely related things that have measured detonation velocities simultaneously with launching shock build-up.

Dr. Macek: One of your standard numbers is 37 kbars for initiation pressure of TNT. This, I believe, was taken from the standard gap test. Is it possible that in a test in which you test a low impulse propellant, that your incident shock would be a rather long one and, therefore, require a lower pressure to initiate the TNT. In other words, your value from ammonium perchlorate of 30 kbars, couldn't it be due to the fact that the shock wave from the ammonium perchlorate is 30 kbars high but it's much longer and therefore initiate the TNT?

Dr. Price: This is perfectly possible. It is part and parcel of the area in which we are doing some work, in which a great many other people are doing some work, that is the actual assessment of the effect of a combination of the maximum amplitude which is all I have been talking about with the pressure time history of the loading. I am thoroughly convinced that it is the pressure time history which is ultimately responsible for the initiation. However, there are certain regions in which the maximum amplitude has given us very good guidance and I think Mr. Jaffe's talk will illustrate another phase of it showing the certain regions in which the amplitude works fine and other regions in which there is a departure presumably due to that pressure time loading history.

Dr. Ball: I hope you have lots of money and lots of people to work because I see lots of work that needs doing.

Dr. Price: We do it all.

Dr. Ball: I assume that your work on ammonium perchlorate has been with a cleaner ammonium perchlorate with no films of fuel on the surface of the crystals or something like that. However, in our propellant systems, we have films of things on the ammonium perchlorate crystals. I see a need for a considerable amount of work in what is the effect of these films between the crystals, not only the thickness of the films but also the nature of the films.

Dr. Price: I think that it has been demonstrated on a large scale that the not only films but possible fuel films are of extreme importance in the sensitivity of these inorganic oxidizing materials and we are not actually pursuing this particular thing at the moment. We have demonstrated that we can make the material more sensitive by putting in a fuel and I think a number of other people have. I'm thinking particularly of Dr. Brinkley's recent publication of ammonium nitrate fuel.

CALIBRATION FOR THE GAP TEST WITH A PENTOLITE DONOR

I. by
I. Jaffe

U. S. Naval Ordnance Laboratory
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The NOL large-scale shock sensitivity test (gap test) was originally calibrated with a tetryl donor (1) to interpret the 50% point gap in terms of absolute pressure. The pressure amplitude at the 50% point, assuming the shape of the pressure pulse to be defined by the amplitude, should be an intrinsic property of a propellant tested under standardized conditions, and should be reproducible regardless of the donor used. To determine the validity of this assumption a standard pentolite donor was made and used in a second calibration. This donor was also used to determine the 50% point of various substances; the pressures obtained at the 50% point were compared to those obtained with the standard tetryl donor.

EXPERIMENTAL

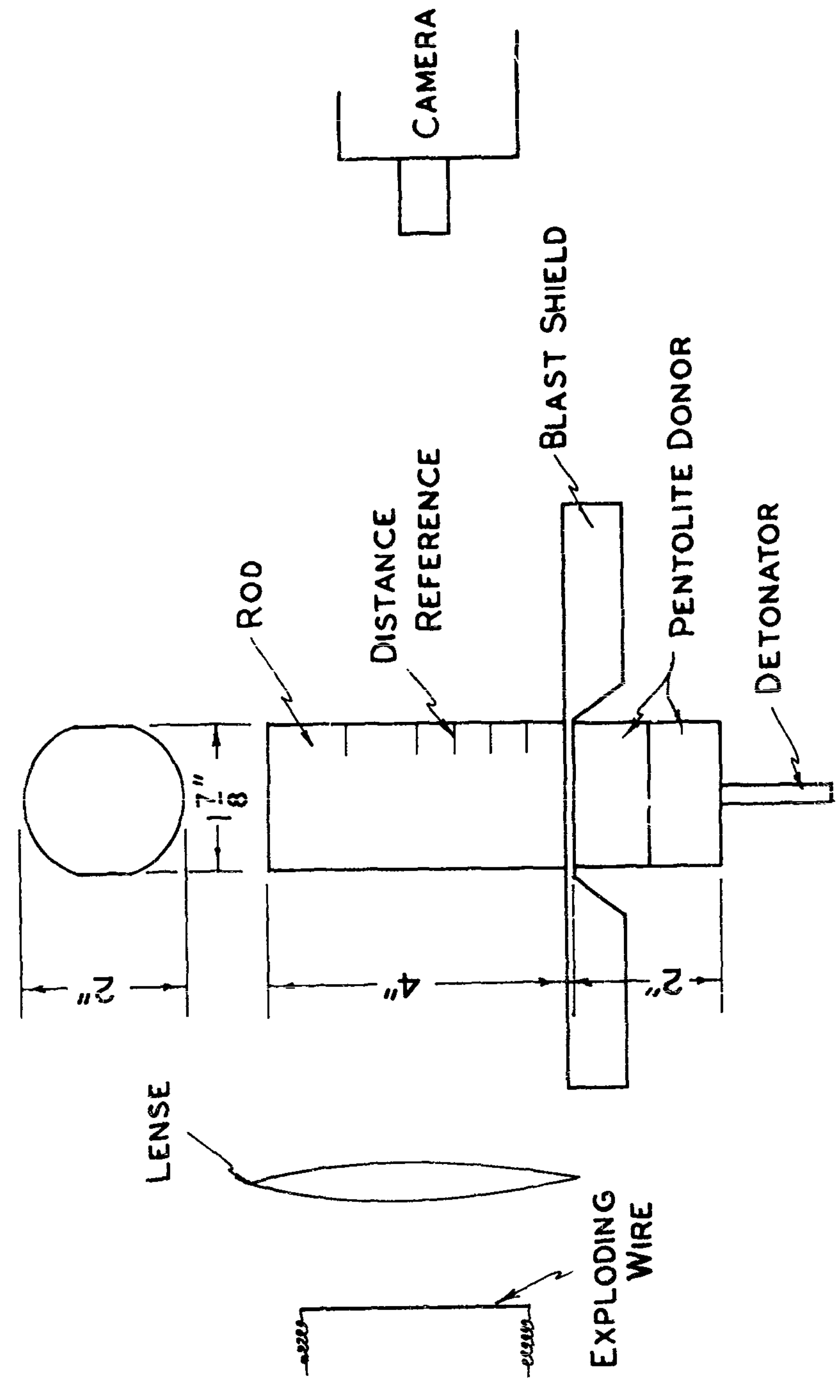
Pentolite Donor

The chemical and physical properties of trinitrotoluene (TNT-Grade I) and pentaerythrite tetranitrate (PETN), which were used to formulate pentolite, are specified in the Joint Army-Navy Specification (2,3). A quantity of these ingredients were sieved separately, using a No. 70 and a No. 100 sieve (U.S. Standard Sieve Series - ASTM specification). That fraction of material which passed the No. 70 sieve and remained on the No. 100 sieve (particle size ranging from 150 microns to 210 microns) was used. One thousand grams of the sieved TNT and an equal amount of PETN was added to a "V"-blender and dry blended for a period of one hour to insure a homogeneous mixture.

The TNT-PETN mixture (pentolite) was placed in a mold, which measured 2" inside diameter, and was pressed on a hydraulic press to a length of 1 ± 0.003" and to a density of 1.56 - 1.57 g/cc which is 91 - 92% of the theoretical maximum density, 1.71 g/cc.

Experimental Procedure

The attenuation of a shock generated by two pentolite pellets in a Plexiglass rod was measured by a streak camera. Figure 1 is a schematic of the experimental assembly. A Plexiglass rod 2" in diameter and 4" long was machined from 1 7/8" sheet Plexiglass. The resulting



FIGURE·1· EXPERIMENTAL SET-UP

rod contained two parallel opposing flat surfaces 1 7/8" apart (see Figure 1) through which the camera could view the shock front as it progressed up the rod. The flat surfaces eliminate any distortion of the light. Calibration lines were inscribed at known distances on the rod.

The rod was set upon two pentolite pellets which were conditioned at 25°C. A blast shield of known thickness was provided to prevent the products of the reaction, resulting from the detonating pentolite pellets, from obscuring the view of the camera. A detonator, used to initiate the reaction, was placed in contact with the donor. The entire assembly was back-lighted by an exploding wire. The approximate speed of the camera was 1.32mm per microsecond.

RESULTS

The data obtained from the experimental records are listed in Table 1 and plotted in Figure 2.

The equation which relates the shock pressure and the shock velocity is

$$P = \rho_o u U$$

where

P = shock pressure
ρ_o = initial density of the material
u = particle velocity
U = shock velocity

To determine a corresponding pressure both the shock velocity and particle velocity must be known. The shock velocity and particle velocities for Plexiglass (4, 5) and similar substances such as Lucite (1, 6) and Perspex (7) have been determined experimentally. These data were combined to give a relationship between shock velocity and particle velocity (1) which was used to calculate a corresponding pressure for each shock velocity determined experimentally under the conditions described above.

It is difficult to determine the velocity precisely for the first ten to fifteen millimeters of the gap. A slight change in the interpretation of the data in this region (shape of the curve) makes for a fairly large change in the calculated shock pressure. The error may be compounded further by the inaccuracies in the determination of the slope and in the equation of state used to obtain the shock pressure. To obtain the best interpretation, a number of equations ranging from a second to a seventh degree polynomial were fitted to the experimental

TABLE 1

Distance vs Time in Plexiglass Rod

Expt. 1		Expt. 2		Expt. 3		Expt. 4	
Time µsec	Distance mm.	Time µsec	Distance mm.	Time µsec	Distance mm.	Time µsec	Distance mm.
0.68	4.5	1.37	7.7	0.78	5.3	0.61	4.5
3.30	17.3	3.26	16.2	2.36	13.3	1.44	8.8
5.16	25.3	5.32	25.4	5.32	26.2	3.51	18.5
7.18	33.0	7.20	32.6	7.22	33.2	7.07	33.3
9.73	41.8	9.86	42.3	9.66	41.6	9.62	42.8
12.15	49.7	12.34	50.9	12.61	50.4	13.31	55.3
15.20	59.3	15.57	61.5	17.16	65.8	17.50	68.6
22.87	83.0	20.24	76.3	19.46	72.8	21.06	80.1
25.00	89.5	23.34	86.3	21.70	79.6	23.96	89.3
26.90	95.0	26.46	95.9	25.25	90.9	26.77	97.8
28.33	99.5			28.33	100.1		

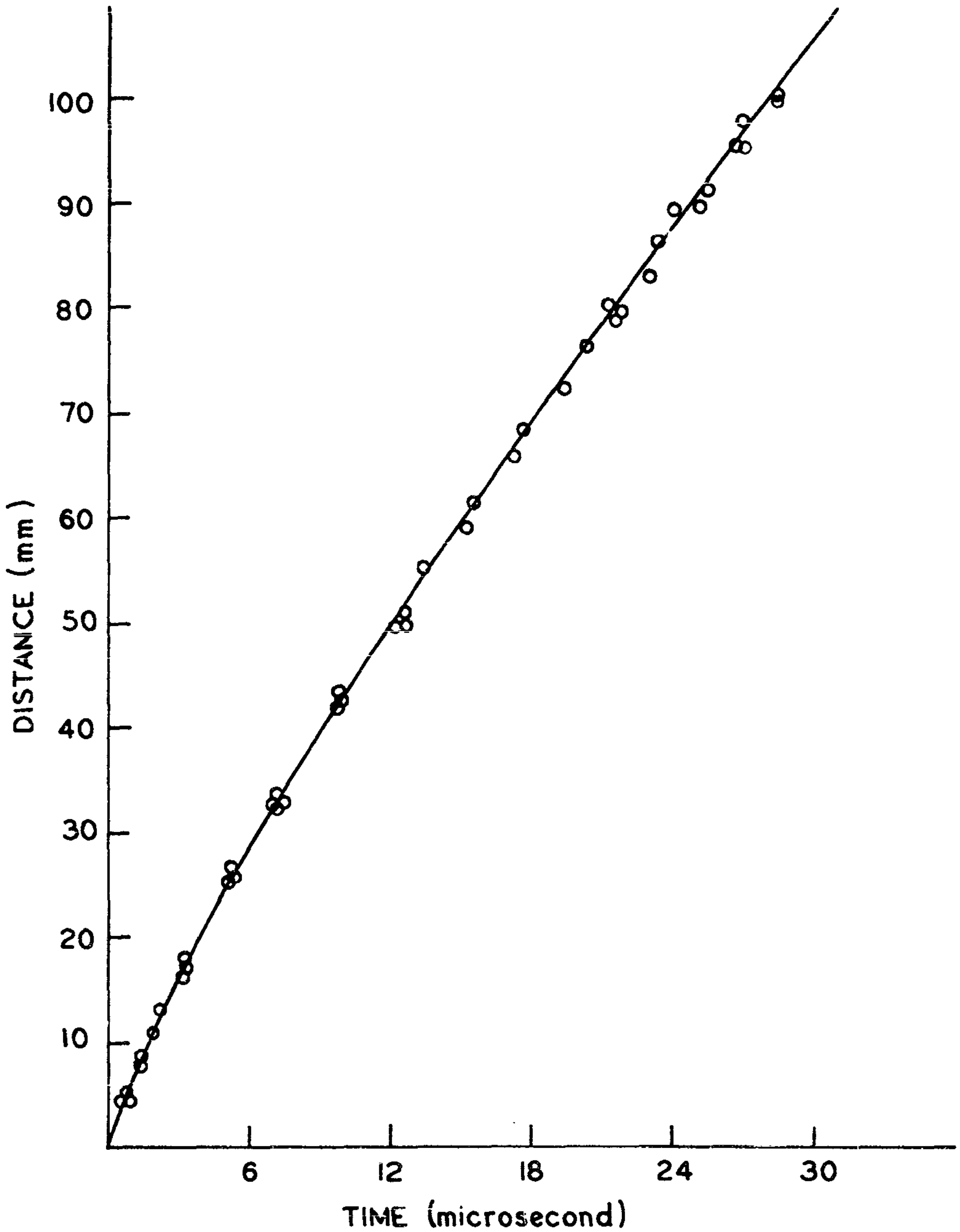


FIGURE 2. SHOCK IN PLEXIGLASS

data by an electronic computer (IBM-7090). A sixth degree equation was obtained which reproduced the experimental data to a fair degree of accuracy. The first derivatives of the equation

$$x = 0.932 + 5.63t - 0.260t^2 + 0.020t^3 - 0.113 \times 10^{-2}t^4$$
$$+ 0.036 \times 10^{-3}t^5 - 0.047 \times 10^{-5}t^6$$

where

x = distance (mm)
t = time (sec)

were used to obtain the shock velocities. Table 2 contains the smoothed data for the shock velocities and the shock pressures. A more detailed discussion of the method of calculation can be obtained from reference (8).

DISCUSSION

The gap used in the NOL shock sensitivity test is composed of Plexiglass, Lucite, cellulose acetate or some combination of these materials. These substances are quite similar and it has been demonstrated (1) that they are equivalent as attenuators in the gap test. Figure 3 shows the relationship between pressure and distance (gap) for both pentolite and tetryl. Both donors were calibrated under similar conditions with one exception: the Plexiglass rod used here was slightly smaller, 1 7/8" between the flat parallel surfaces as against 2" in the earlier work with tetryl. This should not affect the results obtained to any noticeable degree. The same equation of state was used in both calibrations to calculate the pressure-distance relationship for the gap. The tetryl curve of Figure 3 was derived from graphical treatment of the data because an analytically fitted cubic in the range 5 - 25 μsec gave velocities only a few per cent higher than those determined graphically (1).

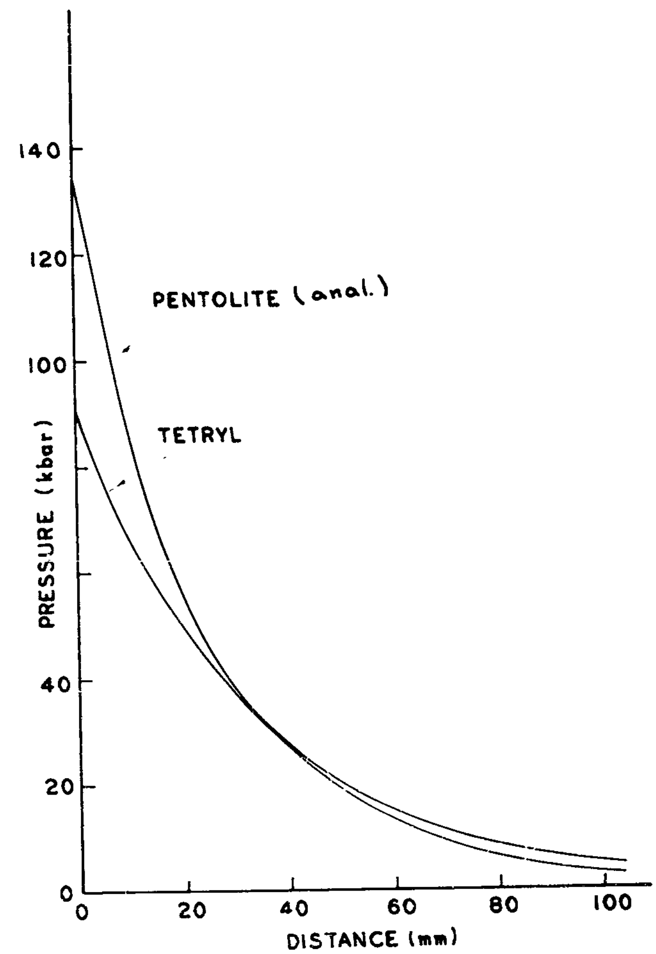
It is apparent that the pentolite donor initially generates a larger pressure than the tetryl. The pressure, generated by the pentolite donor, is attenuated rapidly. After 9mm it is within the tetryl pressure range and after 25mm (1") of travel its curve is similar to that of the tetryl. From this point on both donors may be considered to give the same pressure amplitude within the precision of the experimental data.

The pressure amplitude at the 50% point as a quantitative measure of sensitivity was further studied by making a series of shock sensitivity tests on several different materials. A number of charges were made from the same batch of materials and the 50% point gap was determined using first a tetryl donor and then a pentolite donor. The results are listed in Table 3.

TABLE 2

Pressure and Shock Velocity as a Function of Distance

Distance mm	Shock Velocity mm/μsec	Pressure kbar
0	5.64	133.4
2	5.49	124.0
5	5.26	109.4
7	5.11	100.0
10	4.88	87.4
12	4.74	79.8
14	4.62	72.8
16	4.49	66.7
20	4.27	56.0
24	4.08	47.6
28	3.92	40.8
32	3.78	35.6
40	3.58	27.5
48	3.42	22.2
60	3.18	14.6
70	3.03	10.7
80	2.94	8.0
90	2.87	6.4
100	2.81	5.0



FIGURE·3· PRESSURE vs GAP

TABLE 3

Pentolite vs Tetryl - Shock Sensitivity

Material	Donor	Gap 50% Point	Pressure kbar	Mean kbar
Comp B-3 (cast)	Tetryl	209	16.4	
	Pentolite	209	18.0	17.2
Nitroquanidine ρ_o = 1.59 g/cc	Tetryl	46	63.0	
	Pentolite	53	74.6	68.8
Nitroquanidine/Wax 95/5 ρ_o = 1.55 g/cc	Tetryl	16	78.8	
	Pentolite	25	103.2	91.0

The pressure amplitude for the same substance measured by the tetryl system and the pentolite system differ by ± 5% for gaps larger than 50 cards (13mm). For gaps less than 50 cards the values differ by ± 8 to 14%, with increasing difference for decreasing gap length (see Table 3).

It can be concluded that the same initiating pressure (to within 5%) is measured by either donor at large gaps. For smaller gaps, agreement between the donors is not obtained because the calibration curves in this region are inaccurate or because the pressure-time loading curves (not measured) affects the results or because both of these factors are operative. For the smallest gaps (highest pressures) it seems that the pressure-time histories of the two donors differ, and that this factor is having a major effect on inducing detonation of the acceptor. In other words, at the highest pressures, pressure amplitude alone does not sufficiently define the shock.

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7. J. S. Buchanan, H. J. James and G. W. Teague, Armament Research and Development Establishment, ARDE Memo (MX) 20/59, April 1959.

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Mr. Saffian: This question isn't really related to the purpose of your paper, but I'm just curious, has NOL - you showed a nitroguanidine wax in one of your slides and gave some data for that - has NOL ever considered that for any real use?

Mr. Jaffe: No, I don't think so. I needed something that I could use at the insensitive gap and all I did was take nitroguanidine and dilute it trying to get a more insensitive material.

Mr. Paulson: Will pentolite boosters replace tetryl in the standard NOL test?

Mr. Jaffe: No, this was another reason why we did this. We've been using tetryl and we have a great backlog of material based on pentolite. You see, the point is this, since we can calibrate the curve, since it doesn't depend upon what donor you actually use, there is really no necessity for using strictly one or the other. We can interpolate from these curves, either working from pentolite to tetryl or from tetryl to pentolite. The answer is no, we won't, we will be shooting tetryl.

A REMOTE OPERATIONS LABORATORY FOR RESEARCH AND DEVELOPMENT OF HAZARDOUS PROPELLANTS

by
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A special laboratory has been constructed at Aerojet-General Corp. which provides the capability of performing by remote operation any process necessary for formulating propellant with new, hazardous constituents. This laboratory was necessitated by the high degree of detonation sensitivity and the critically short supply of the compounds that are of most interest in present-day propellant research. Operations in the laboratory are limited to a scale of one pound of explosive substance, but the facility is separated into cubicles such that several of these one pound operations can be conducted simultaneously.

Figure 1 is a diagram of the building layout. The activities of the entire building evolve upon the work carried out in the operations area, Number 5. In this area are to be found the eight cubicles, with 1" thick steel walls and 7" thick Plexiglas windows between the operators and the operations. A photograph of this portion of the building is shown in Figure 2.

Two types of manipulators are used in the process cubicles, the master-slave type for intricate operations, and the through-wall type for more simple operations. Both types may be changed from one cubicle to another from the operator's side of the protective wall. Enough pairs of the inexpensive through-wall manipulators are available to equip nearly all the cubicles, but the high cost of the AEC-designed master-slave manipulators makes it necessary to conduct operations with fewer pairs. The apparatus for moving the master-slave manipulators from one cubicle to another consists of a chain hoist and bridge crane, by means of which two men are able to effect the transfer in twelve minutes.

Each process cubicle has a floor space four by four feet square, and is ten feet high for apparatus setups of extended height. The operator has a viewing window 18 x 24" square. The thickness of Plexiglas in the window is 7", and the protective wall between the operator and the operation is 1" thick mild steel. The thicknesses of the protective walls and windows in the cubicles are adequate to withstand the explosive force of one pound of the most powerful explosive calculated to date, including the shrapnel effect from an explosion in glass or steel. Adjoining cubicles are separated by 8" walls of reinforced concrete. At the rear of the cubicles are blowout panels.

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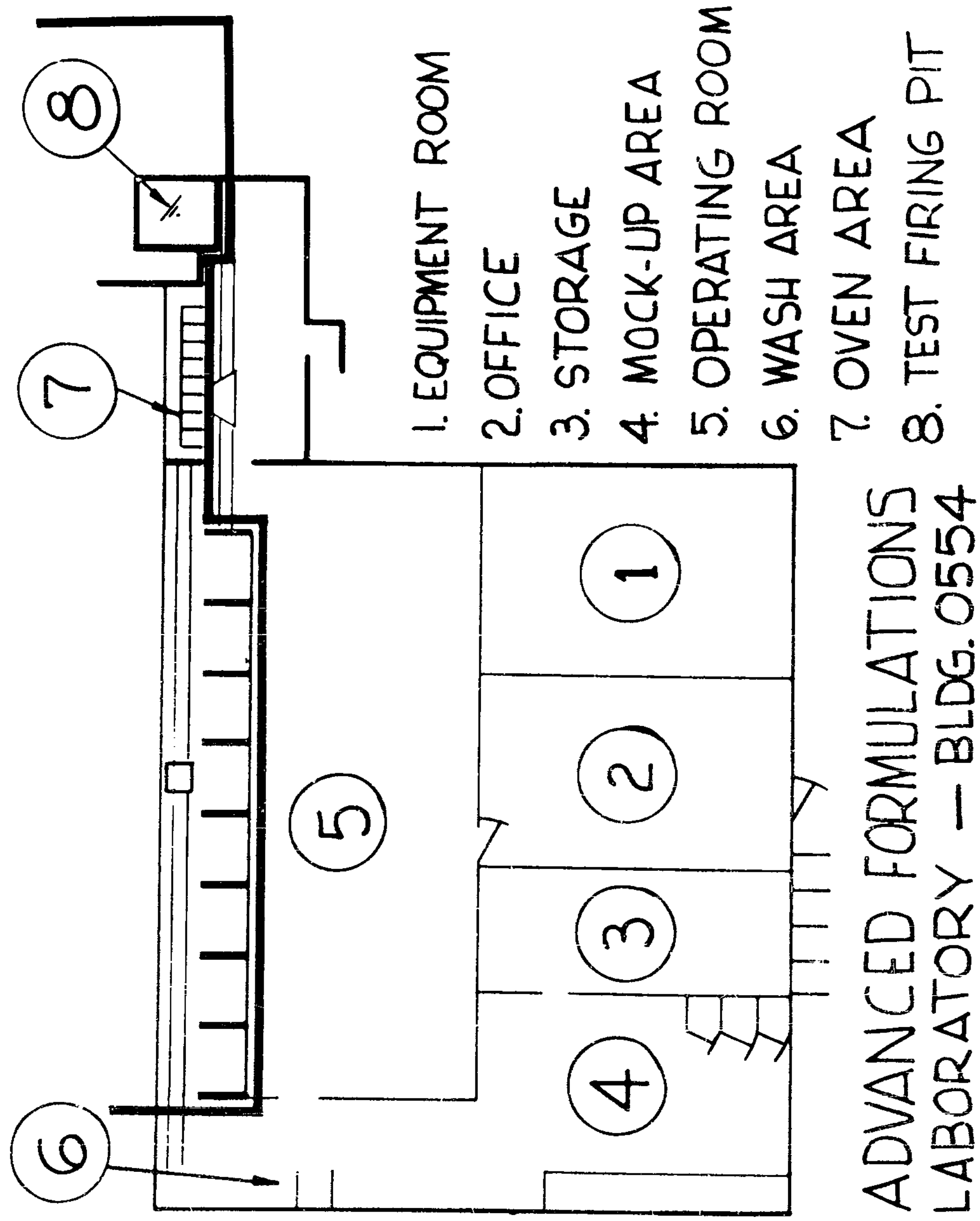

Figure 1

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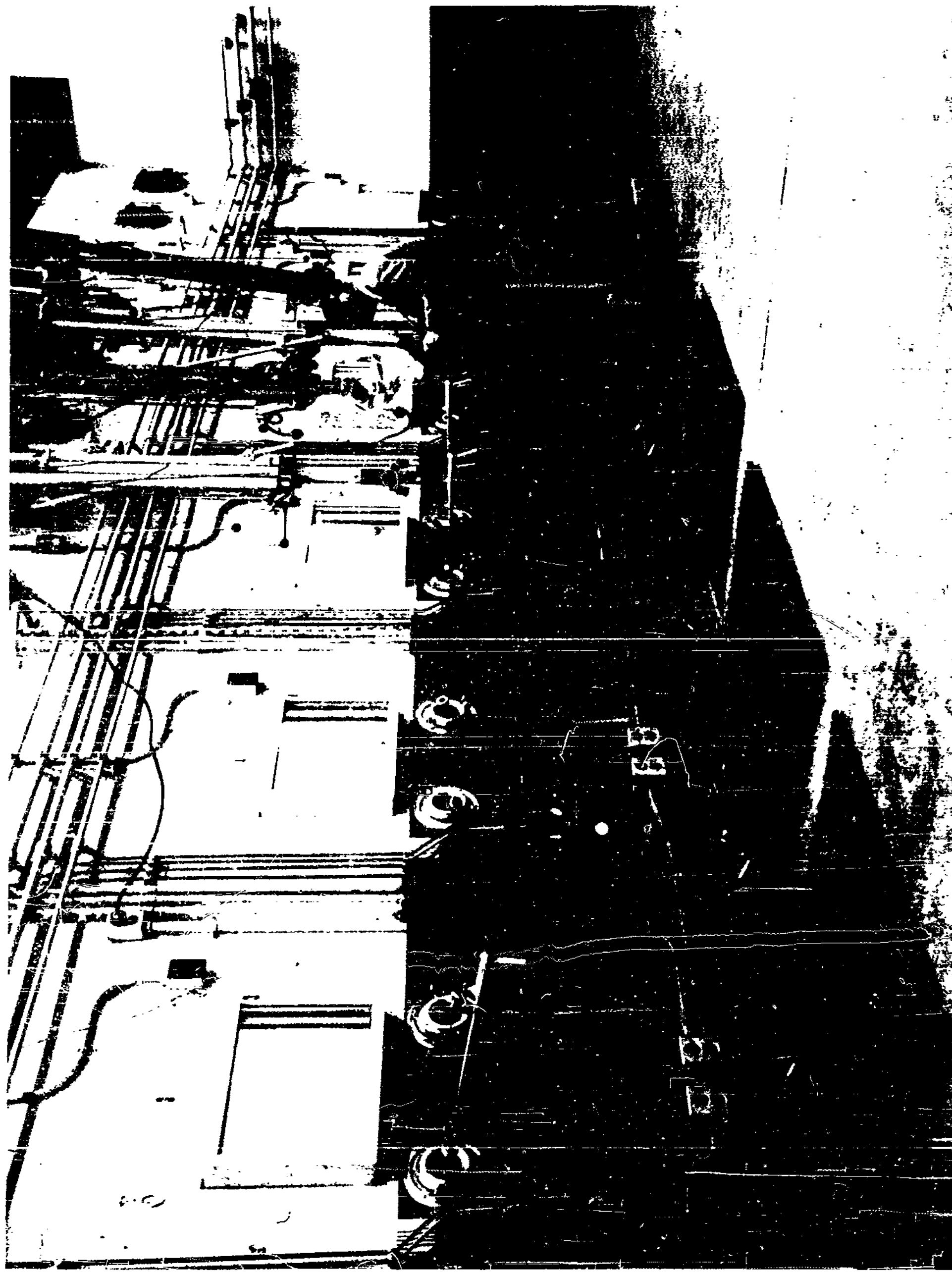
Figure 1



Operations Cubicles
Figure 2

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Operations Cubicles
Figure 2

Referring again to Figure 1, the laboratory has, in addition to the process cubicles, a row of eight ovens and a firing bay for one pound test motors, both served by an extension of the remote conveying system for the cubicles. The process cubicles, the ovens, and the firing bay are all provided with remote manipulation capability, so that it is possible to introduce raw materials at one end of the remote conveyor line, synthesize and purify the hazardous compound, mix, cast and cure the propellant, and perform the test firing at the other end of the conveyor line, all under one roof. In Figure 1 the explosive area, which personnel never enter, is marked by a red line.

The outstanding feature of the laboratory is a high degree of versatility, which allows unit processes or operations to be carried out that range all the way from organic synthesis to propellant machining and mechanical-property testing. The next most advantageous feature is the remote conveying system, which is so integrated that hazardous materials can be transported from one unit operation to the next without interruption of other operations and without manual handling of any kind.

A further feature of the laboratory is a mockup and setup area, which consists of three simulated process cubicles of lightweight construction. These mockup cubicles are fully equipped with laboratory service lines and manipulators, but have thin glass windows and plywood walls in place of the heavy protective construction in the genuine process cubicles. The purposes of the mockup cubicles are: (1) to provide space for mechanical "setup" operations in preparation for the hazardous process, prior to introduction of the dangerous material; (2) to permit a prior "rehearsal" of the dangerous operation to be conducted, using an inert simulant for the dangerous substance; and (3) to provide a training space for personnel to acquire skill in the use of the remote manipulators. A photograph of an operator practicing in the mockup area is shown in Figure 3.

The high degree of versatility in the laboratory is achieved by "pallets" in the cubicles (platforms for mounting the laboratory setups) which permit shifting from one unit process to another without "down time." Each pallet is equipped with apparatus that makes it specific for one unit process or unit operation, and each pallet is portable so that it can be moved in or out of a cubicle, or between the process cubicle area and the mockup cubicle area. The same remotely operated conveying cart that serves to transfer hazardous material from one cubicle to another is used for transferring the pallets between cubicles.

(At this point, a ten-minute silent movie is shown, depicting activities in the remote operations laboratory, with narration by the author.)

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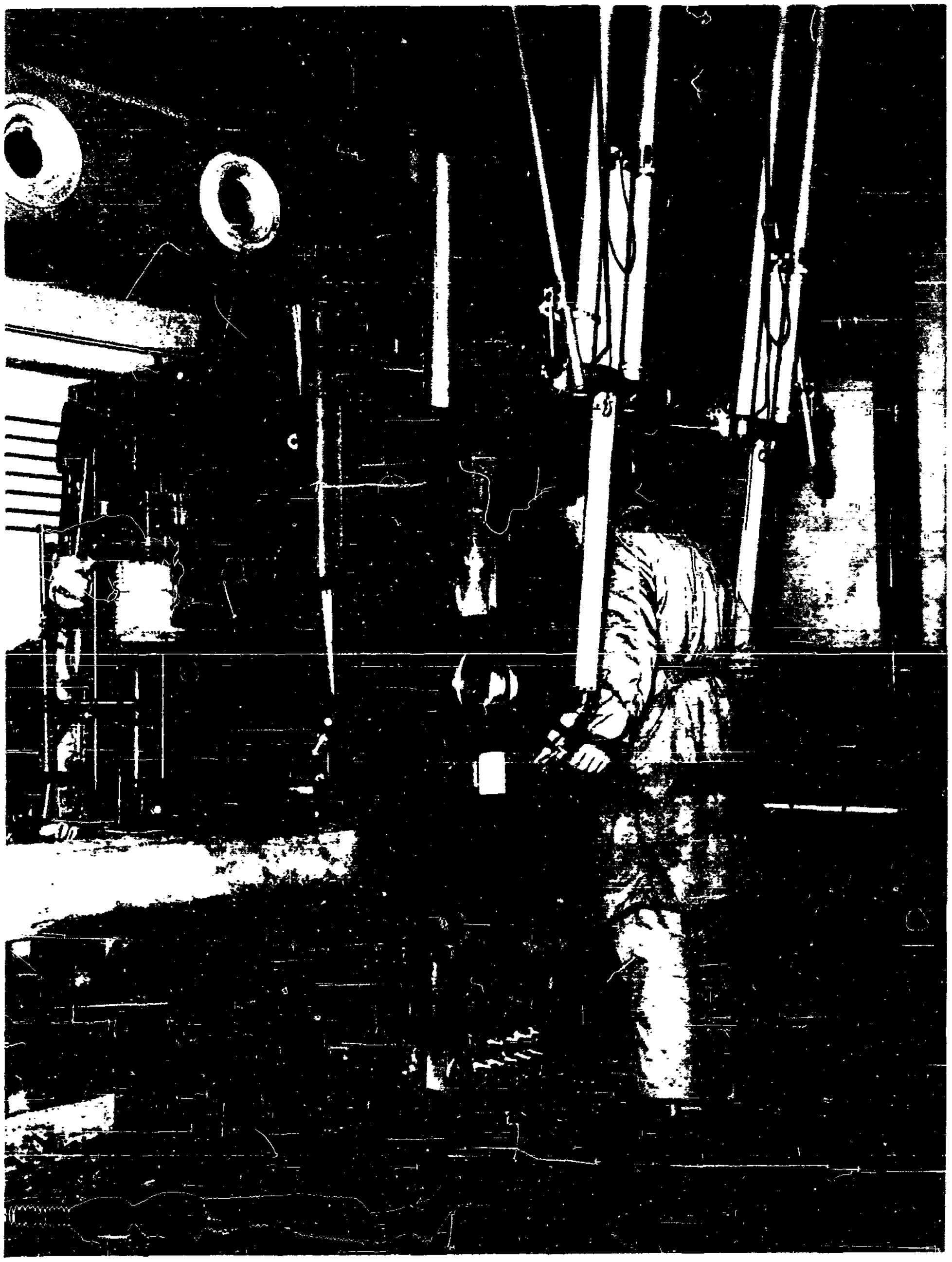

Mockup Cubicles
Figure 3

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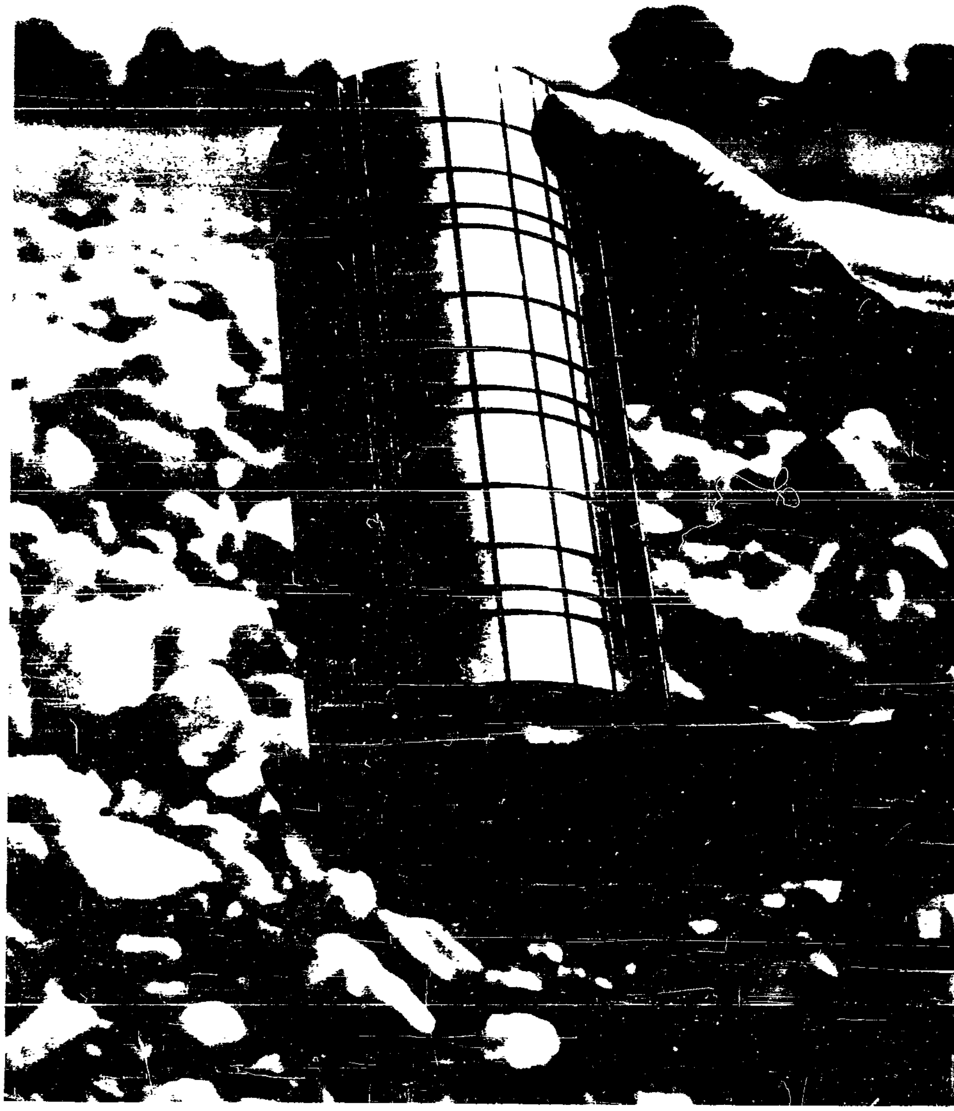
Mockup Cubicles
Figure 3

In arriving at the design criteria for walls and windows, field tests with standard explosives were performed on simulated cubicles of various construction. Figure 4 shows the "grenade" type of steel container used for the explosive charge. This container was designed to produce shrapnel particles of varying size. Figure 5 shows the test cubicle after the firing. The 1/4" and 1/2" thick sides of the cubicle were perforated, and the 3/4" side was dented, but the 1" thick side held consistently.

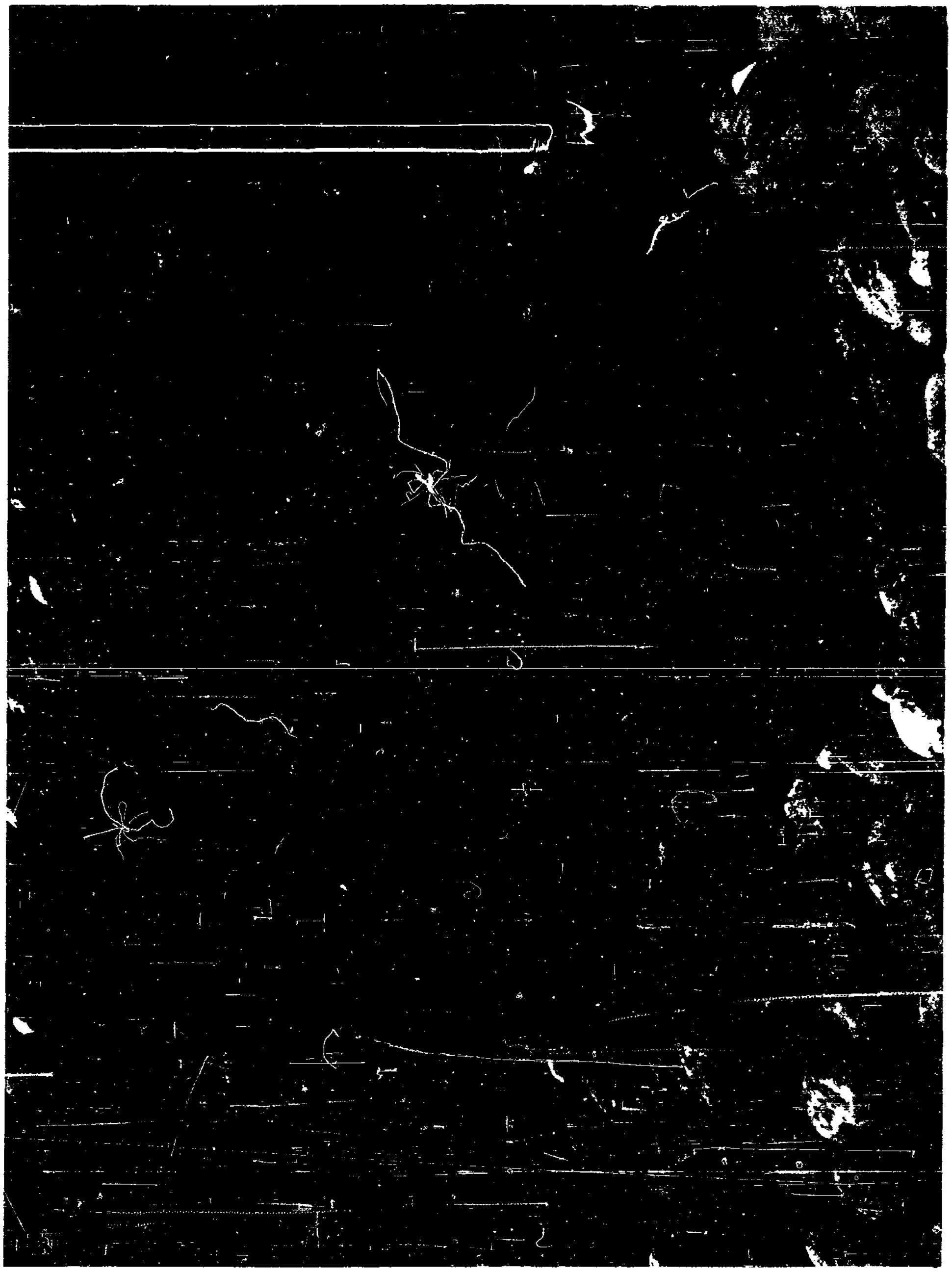
Figure 6 shows a similar field test of the window construction. In this particular test, the inside window was thoroughly broken, but the window thickness nearest the operator was only scratched. From repeated tests of various construction, the design arrived at was a 4" thick pane on the explosion side and a 3" thick pane on the operator's side, with a 1" air gap between the panes.

To summarize, the end objective of the design and testing has been to develop a facility which not only is adaptable to any given unit operation that may be encountered in propellant research, but which can efficiently carry out successive operations without requiring manual transporting of dangerous substances between operations. A secondary objective has been to provide the capability of changing setups without closing down the whole process area in order that workmen may safely enter. It is believed that the system of remotely conveyed pallets described here is the most economical means of meeting these two objectives.



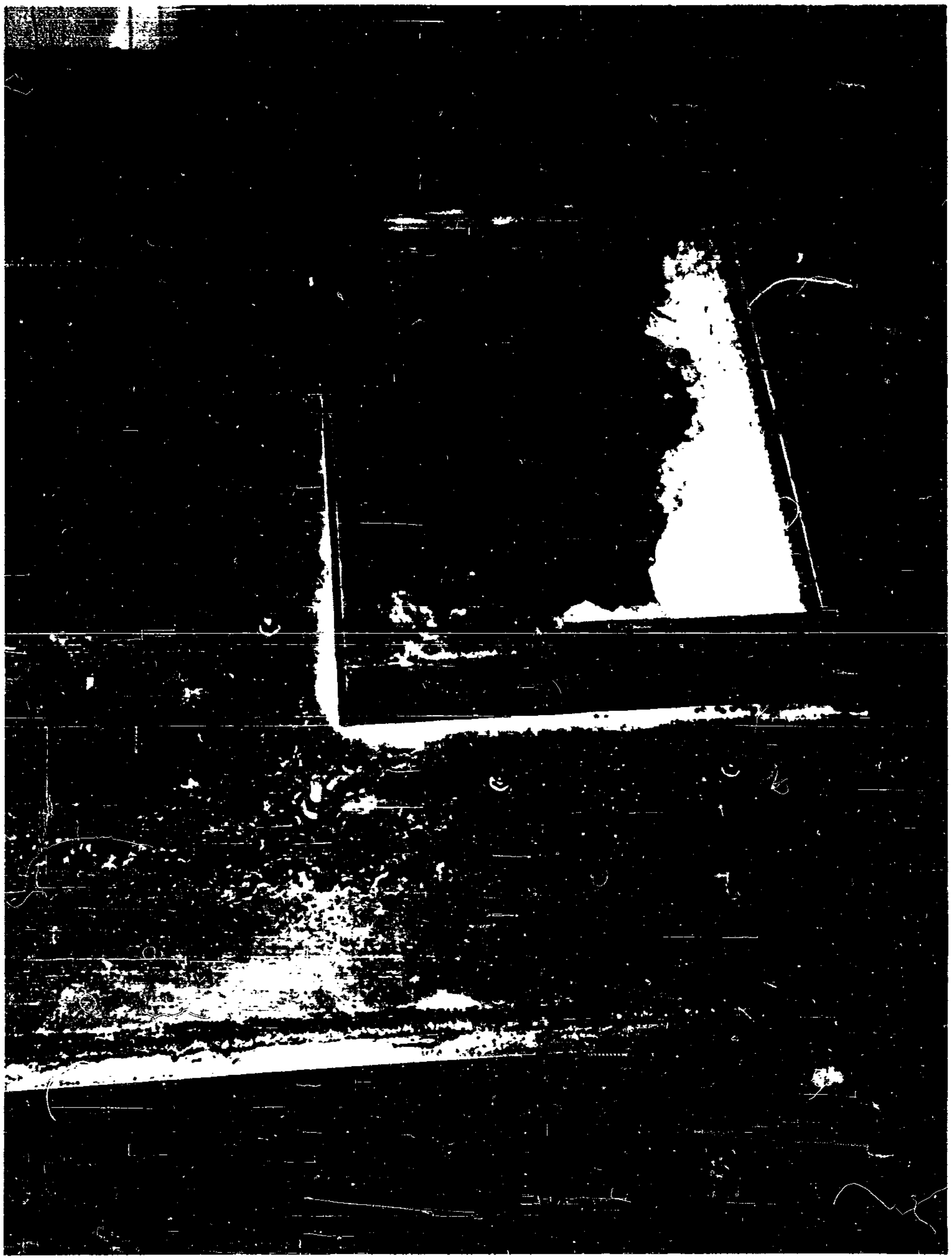
Container for Shrapnel Testing
Figure

Container for Shrapnel Testing
Figure 4



Test Cubicle after Explosion
Figure 5

Test Cubicle After Explosion
Figure 5



Protective Window After Test Explosion

Figure 6

Protective Window After Test Explosion

Figure 6

Mr. McBride: Could you tell us what type compositions you intend to use this for or what type composition necessitates this type of facility?

Mr. Parrette: If we get into the Confidential classified area, we have used it for hydrazine perchlorate oxidizer, hydrazine nitraform oxidizer and aluminum hydride. The main objective we have is to be able to use any of these new beasts of unknown potential danger all the way down from the one pound level, i.e., the manipulators are facile enough so that one could work even at 1/10th gram level and who knows what the explosive hazard is in synthesizing NF_2 type compounds or possibly nitronium perchlorate. Is this a detonation hazard? Certainly it is a fire hazard. The main objective here is to work at a low level until we do have some idea of the explosive sensitivity or the deflagration hazard.

Mr. Parrott: I have a couple of questions. I wonder if you could give us an estimate of the cost of the facility and second, something I think you were just about to touch on, how would you go about deciding whether an experimental propellant composition was safe enough to be scaled up for manufacture in more conventional facilities?

Mr. Parrette: The cost of the facility without manipulators including the remote conveyance system was very close to $200,000. Your second question is in Mr. Manfred's paper which is scheduled for tomorrow. That's the only subject it has, so I'll defer your question to his paper tomorrow.

Mr. Fox: It wasn't clear in the presentation, but do you have provision for transferring the completed motor into the firing cubicle remotely and arming the motor remotely?

Mr. Parrette: We have potential provision for it, we have not yet done it. You probably noticed the firing bay at the extreme end of the oven area. We have the concrete bay, we certainly know it's adequate for one pound test firing even in the case of a complete detonation. We have not yet geared ourself up to make the intricate aligning adjustment in all the quite tricky mechanical operations to prepare the motor for test firing. By next year's symposium, I hope to report that we've carried the propellant all the way from the synthesis stage to the test firing stage for thrust, but we have not yet done so. We are using the test firing bay for explosive initiation tests of susceptibility to detonation.

Mr. Jezek: Why did you people put 4" of plexiglass on the inside and three on the outside, why not seven on the inside and let it go at that?

Mr. Parrette: In designing these windows, one runs into the problem of parallax with too deep a window cutting off his cornerwise vision and also if the window extends too far into the operating cubicle, it hampers

the operation, the manipulation with the remote manipulators. I think many authors have demonstrated that several layers of given material engrossing a given gross thickness are better than a single piece of material of that same thickness and we settled for just two layers. The other complication is that each layer is an interface between glass and air and you have an optical problem. This may not be the optimum design for a one pound window of minimum thickness but we know it works and it does not interfere with the manipulation set-up that we have.

FACILITIES AND EQUIPMENT FOR REMOTE OPERATIONS IN RESEARCH AND EXPERIMENTAL PRODUCTION OF SENSITIVE PROPELLANT CHEMICALS

by
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Although du Pont's Eastern Laboratory had many years of experience in developing explosive products, the decision to enter the propellant research field presented a real challenge. Whereas most explosives research had been performed manually using chemicals whose physical properties were quite well known, it was soon evident that the synthesis of new propellant chemicals via pioneering routes demanded a complete change in research methods.

Three principles for accident prevention became apparent in the new program.

First, that quantities must be kept to a minimum.

Second, a hands-off or remote policy must prevail, and

Third, proper shielding from blast pressure and missiles must be provided.

Although this paper will deal principally with the facilities and equipment required for the hands-off and barricade phases of the program, mention must be made of the need for adherence to quantity limits. One might think that the average researcher had received his early training in a grocery store where a pound, gallon, and bushel are the units of measure. Demonstrations of the destructive force in 2 grams of explosives from the standpoint of danger to fingers and eyes and a "large-scale" shot in which 13 pounds of explosives was detonated in a missile test were sufficient to convince most of the researchers of the necessity of working with small quantities of energetic materials. The accidental destruction of several pieces of equipment and hoods was necessary to convince the remainder.

I shall spend a few minutes on the 13-pound missile test shot in which a 6" O.D. annular charge 12" tall was detonated in a simulated motor casing whose wall was stepped to provide missiles from 1/8", 1/4", 3/8", and 1/2" wall sections. Four steel plates (1/4", 1/2",

3/4", and 1" thick) which formed the walls of a box were used as witness plates. Slide 1 shows the assembly, Slide 2 shows the earth cover which was used to reduce the noise and retain the fragments, and Slides 3, 4, 5, 6, and 7 indicate the damage wrought by the detonation of the 15 pound charge.

The destruction to a simulated hand by the energy released by 2 grams of nitroglycerin will be shown in a later slide.

Some of the standard research facilities at Eastern Laboratory were satisfactory for propellant research, particularly the autoclave barricades. Three major facility changes were made; namely, alterations to the standard laboratory hood, construction of a 25-gram limit laboratory hood, and construction of a 2-pound limit synthesis cells.

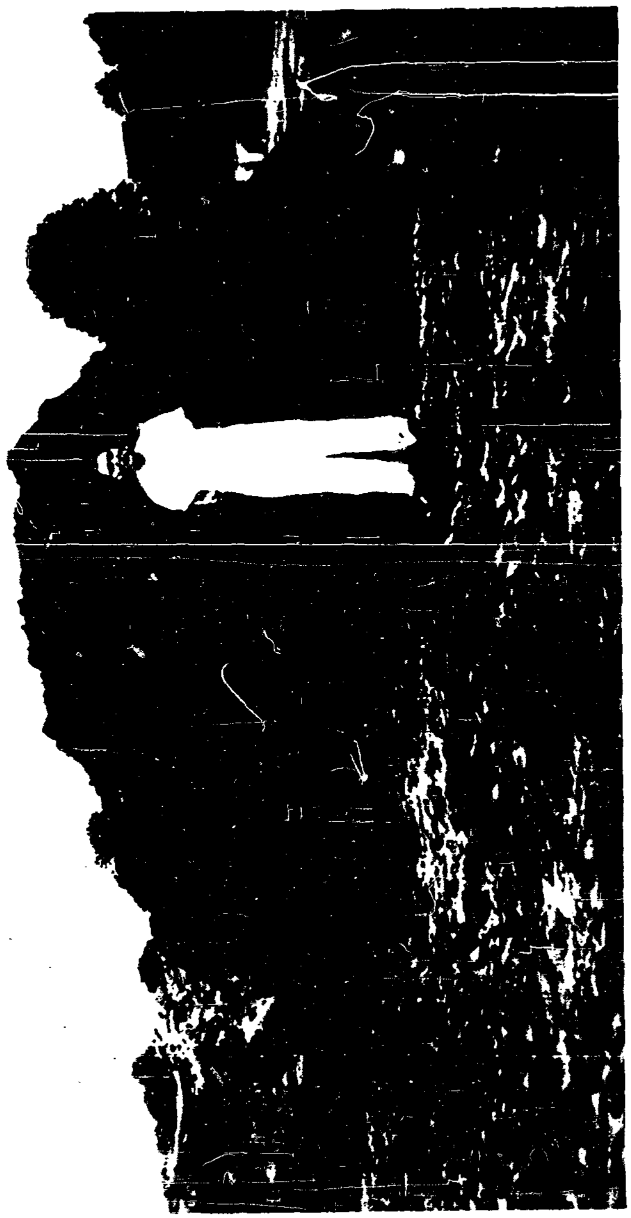
Alteration to the standard laboratory hoods included sheathing the exposed ends with 1/8" steel plate to provide a missile stop and to retain the "transite" which can fragment and become a hazard. The top panels were secured and protected by steel or plywood if they were frangible and each hood in general was examined from a missile standpoint to determine if external light fixtures, etc., could become hazards or could be dislodged and produce injury.

Each hood was provided with two or more slideable "Lucite" shields each 3/4" thick and each hung on a dual door track for easy positioning. A steel channel at the bottom with barricaded entrances for cords, etc., was provided to hold the moveable shields in position and to protect the operator from missiles which might exit beneath the shield. Two-gram explosive limits were established for these hoods.

The 25-gram explosive laboratory hood is 7 feet wide x 3½ feet deep with a 33" high opening across the front. This opening is completely closed by 1" "Lucite" panels which are hung from a three-track channel. Five 24" wide panels are provided. The basic structural material is ¼" steel plate and a full blow-out panel is provided across the back. The unit is operated with the "Lucite" panels closed and the operator wears earmuffs. The unit was tested by detonating 50 grams of NG in a glass bottle which was located 12" from the front shields. The blow-out panel was pushed completely out of the back and the front panels fell into the hood after they had bowed outward 2 to 3". Slides 8 and 9 show the hood before and after the test.

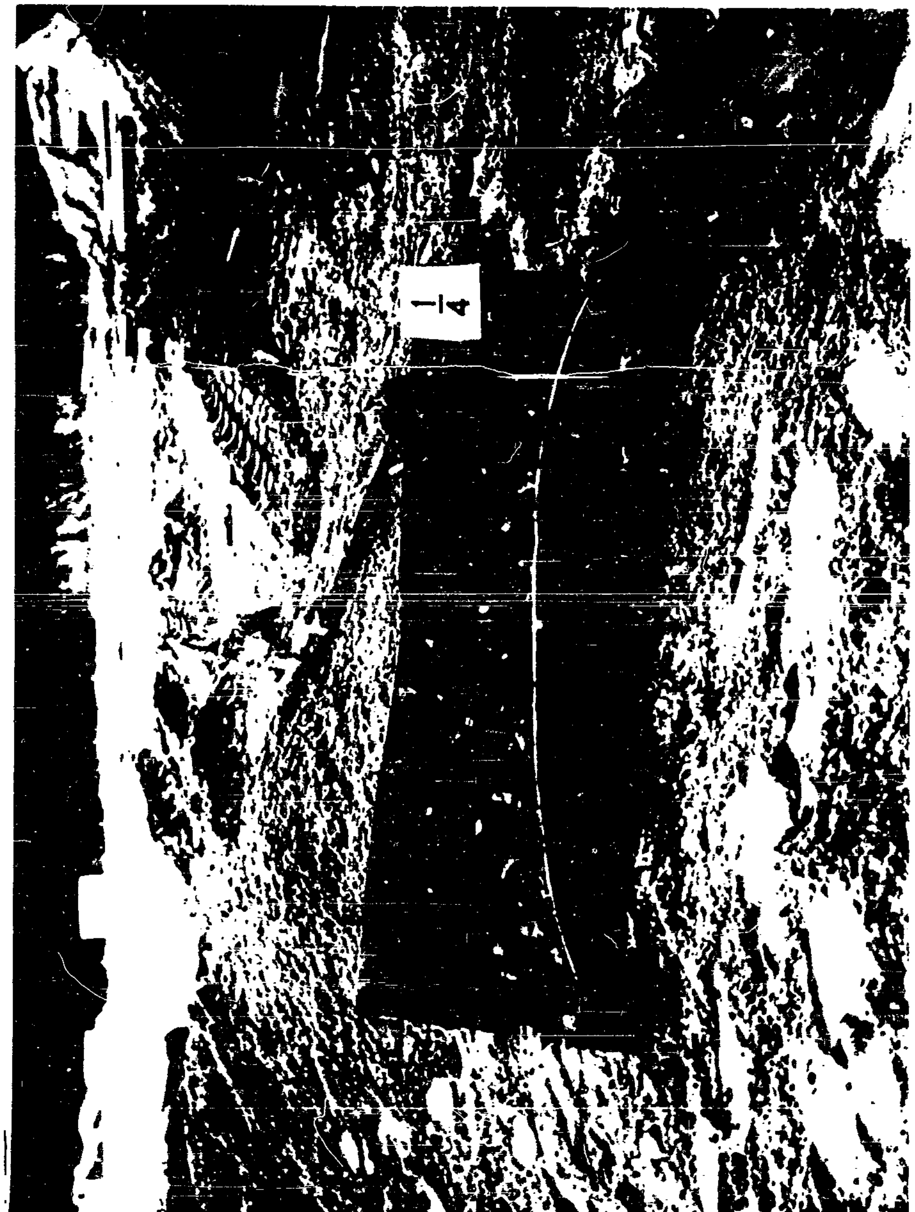
A 6' wide x 6' deep x 10' high steel synthesis cell was fabricated from ½" thick steel plates. This unit was test-fired with 2½ pounds of bare explosives. The unit as shown in Slide 10 stands on end and is open on the side opposite the Control Room. The 4200-pound unit was bulged slightly by the test shot and moved back slightly on the sand base. Final installation was made by welding to steel "I" beams which

Slide 1



Slide 2

Slide 3



Slide 4

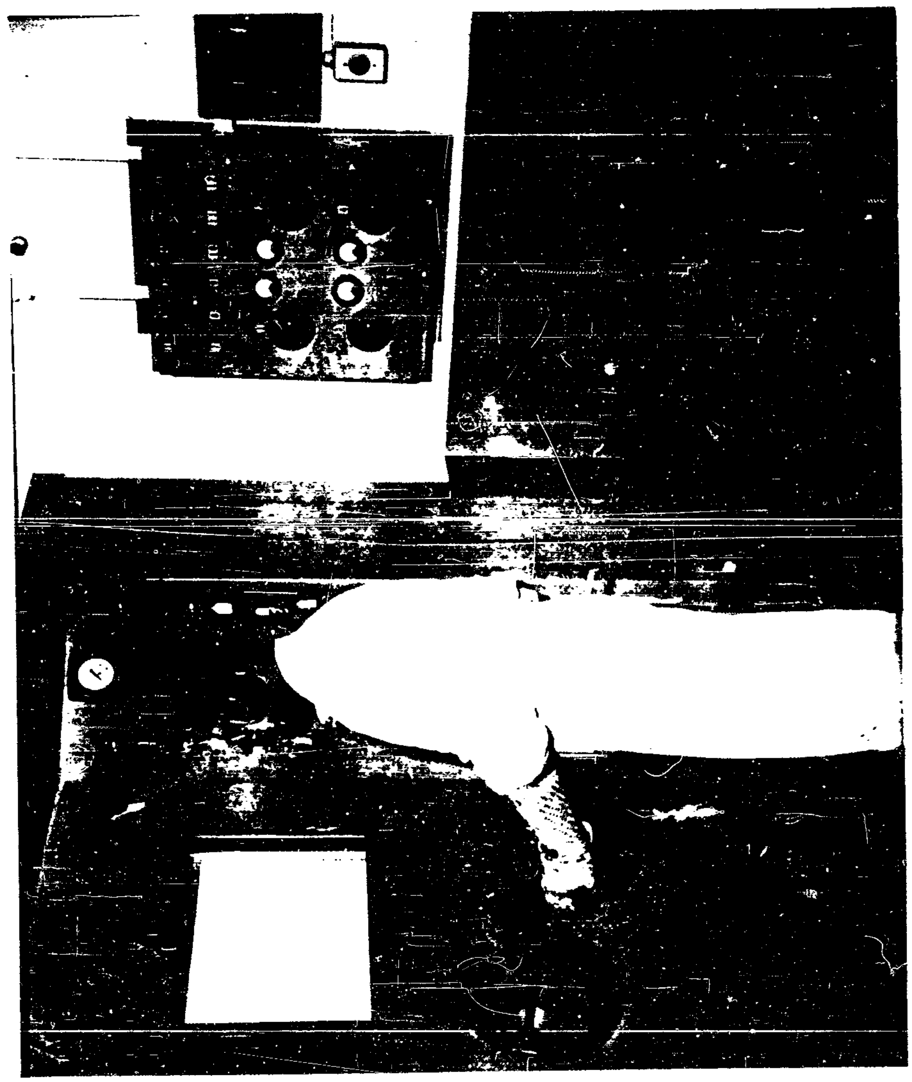
Slide 5

Slide 6

Slide 7

Slide 8

Slide 9



Slide 10

were imbedded in concrete. A multiple look-through window comprising a 3" thick "Lucite" panel and a 4" "Lucite" back-up panel was provided in some models. This window sustained blast pressure and fragments from a 2-pound test shot made in a section of heavy-walled steel pipe.

The hands-off policy required that we develop an array of small remote tools which could be used in our 2-gram hoods and other equipment which would function in the 25-gram hood and synthesis cell.

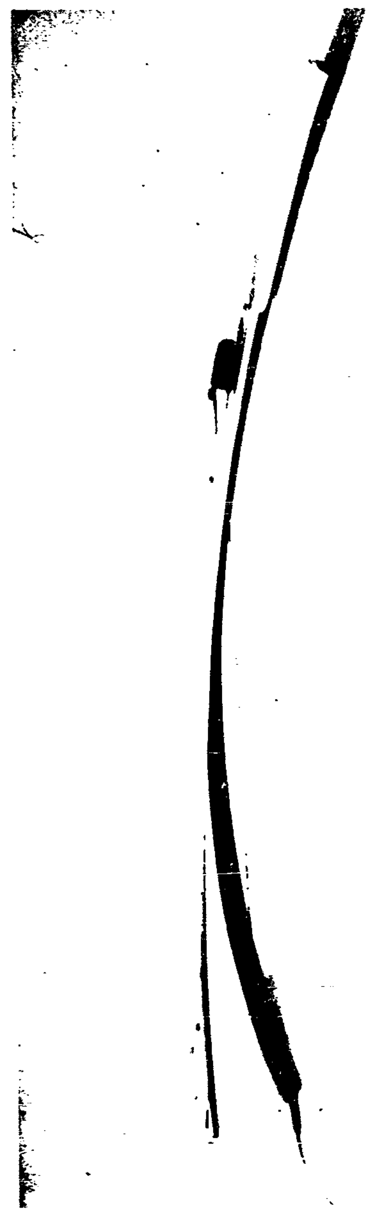
Slide 11 shows a remote pipette which is used to transfer hazardous liquids from one container to another or is used to introduce diluents into a neat sample. It is used as a remote means for adding liquids to propellant mixes. The device is made by drawing, using glass-blowing techniques, a 4" capillary on the intake end of a 145mm polyethylene pipette and a 26" long capillary on the other end of the pipette. The long capillary is drawn in a manner which preserves a full pipette diameter on a short section which accommodates a rubber bulb. This pipette is mounted on a curved piece of marine plywood.

An array of wood tools used for holding small glass bottles, for screwing and unscrewing caps, and for removing slip covers is shown in Slide 12. These are 3-4 ft. long and are used by an operator who stands behind a slideable "Lucite" shield and operates with a gloved hand and gauntlet wrist cover. A 2-gram shot at the end of one of these tools will destroy about 6" of the stick. Earmuffs are worn by operators.

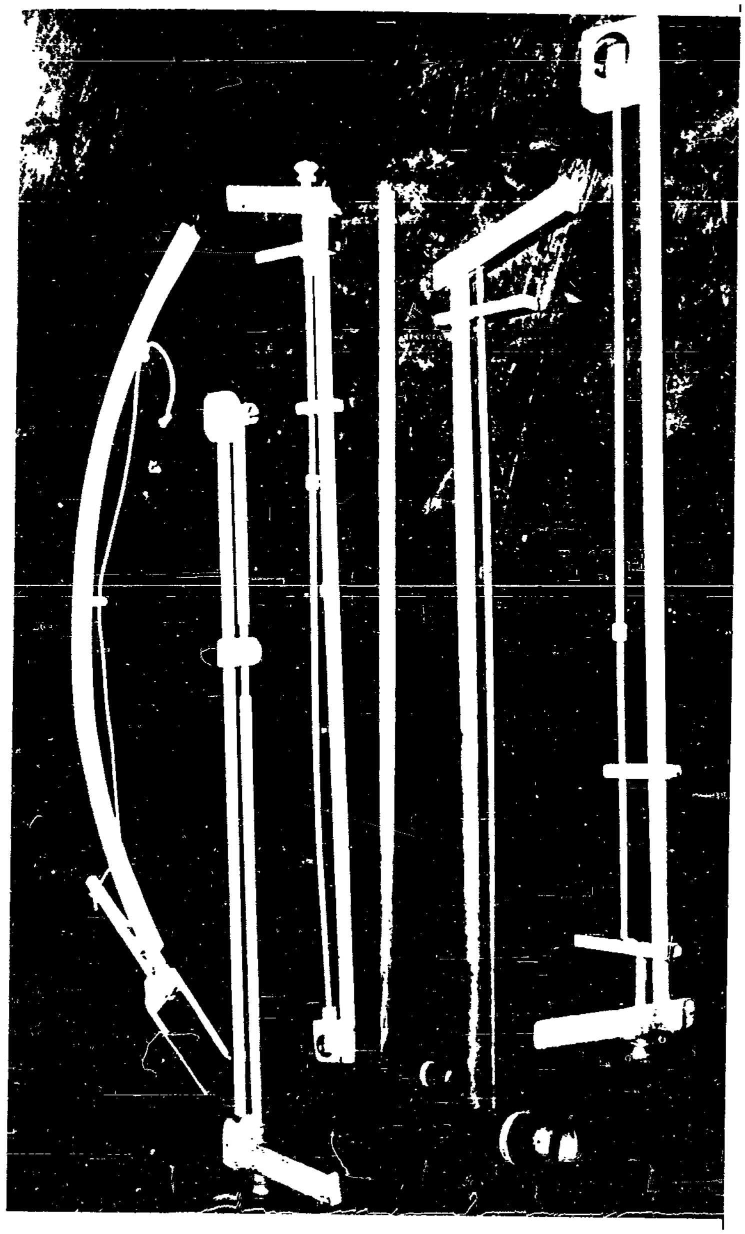
A simple stopcock turner was fabricated using 3/8" diameter soft sluminum tubing and a speed-o-meter cable from a 1962 Chevrolet. Nylon or "Delrin" heads are fastened to the square ends of the cable using two opposing Allen set screws and the back of the head is counterbased to ride on the aluminum tubing and serve as a bushing. These stopcock turners are introduced into the hood via bushings located above the operator. The soft aluminum can be bent to almost any configuration and the heads will remain free to turn. Slide 13.

One of the work horses of our remote operation has been the hydraulic jack which operates on tap-water pressure and comprises a $1\frac{1}{2}$" stainless cylinder (Bimba) and a four-way hydraulic valve (Versa). The unit is shown in Slide 14 and is used to raise and lower platforms and to raise and lower an extended rod on which is mounted a stirrer motor or other equipment. Such a rod which passes through a Lazy Susan table which can be turned remotely, can be used to transfer materials via pipettes, and perform other multiple operations.

Manipulators mounted on sliding rods in $2\frac{1}{4}$" ball sockets are used in most hoods and synthesis cells for remote manipulation. These are purchased from General Radiological Limited in England. An assortment of heads is available. These heads have been altered to suit specialty

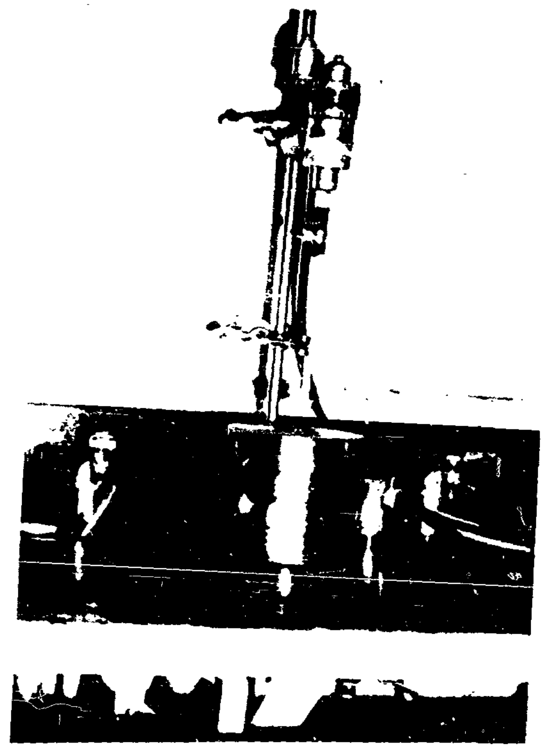


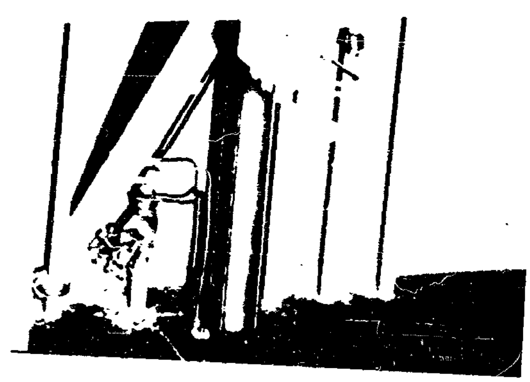
Slide 11



Slide 12

Slide 13





Slide 14

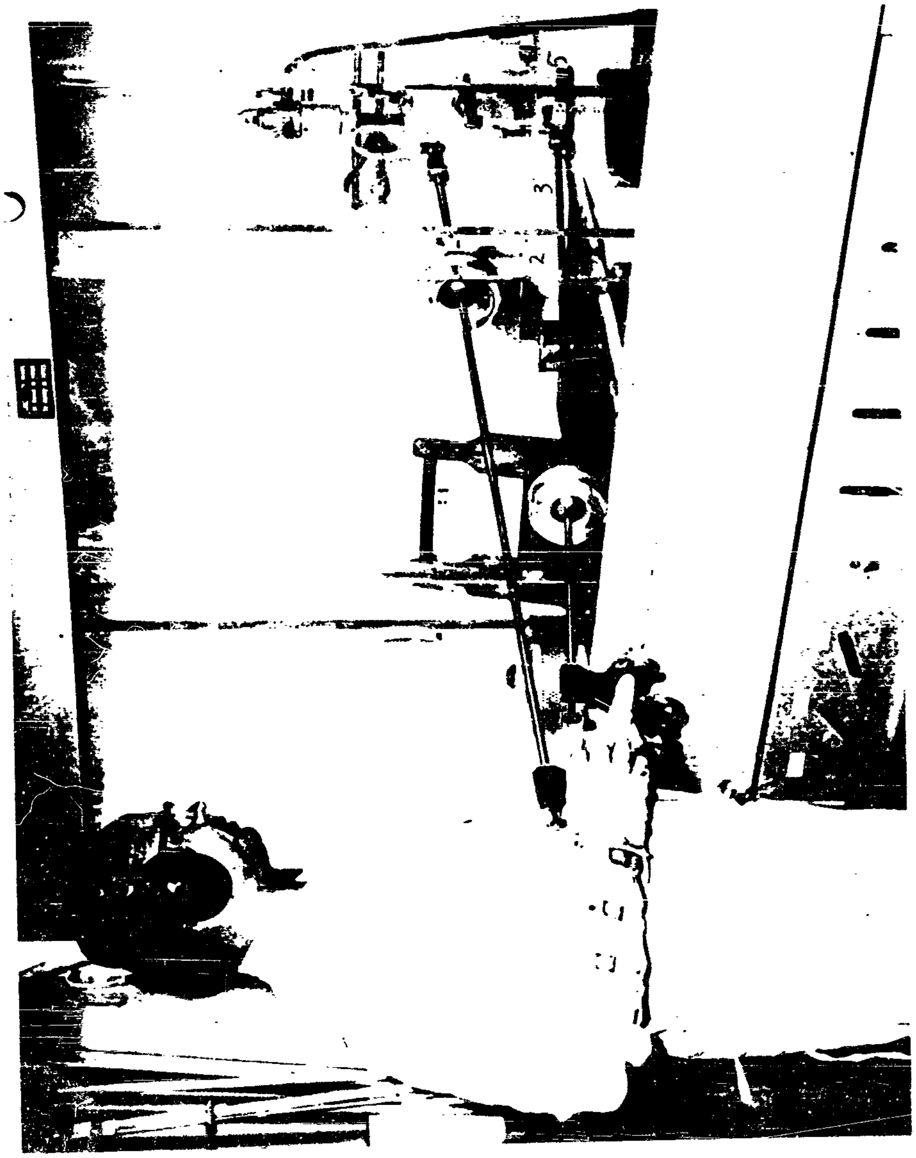
jobs. Slide 15 shows an assortment of these heads. A test ball joint mounted in a steel plate sustained a 1/2 pound PETN detonation. The charge was located 18 inches from the ball. High-speed movies indicated the rod of the tong moved at an average speed of 24 feet/second during the first second of travel. The rod's movement was arrested by the portion of the head which would not pass through the ball opening. When using these tongs in the 25-gram hood and the synthesis cell, racks are provided for various heads so that heads may be interchanged without opening the hood front or entering the cell.

Many auxiliary pieces of equipment have been developed to complement the remote handling equipment used at Eastern Laboratory. Among these is the polyurethane tote barricade. The unique properties of blends of du Pont's "Adiprene" with respect to its ability both to withstand gas blasts and stop missiles have led to a potting process to produce containers for laboratory quantities of sensitive propellant chemicals.

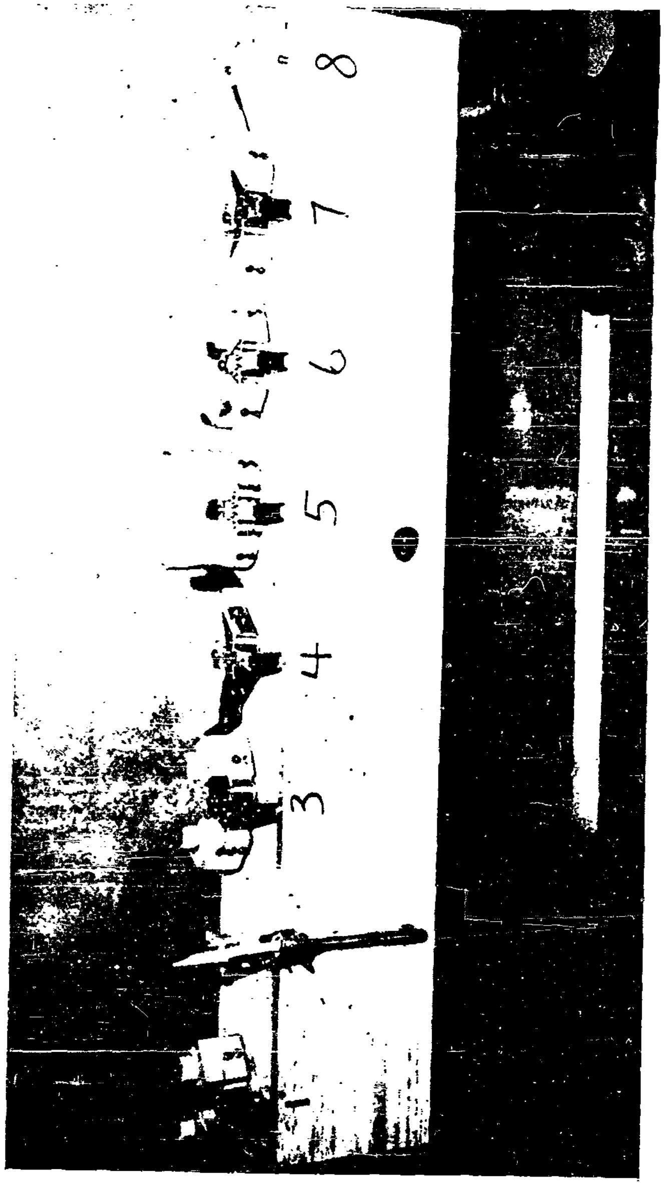
Small glass vessels potted in "Adiprene" using 1-pint and 1-gallon paint cans for molds will sustain detonation of 2 grams and 15 grams of explosives, respectively, without rupturing. These vessels are used at Eastern Laboratory for processing, storage, and transportation of hazardous materials. Although gasses and fragments are ejected from the top of tote barricades, we have found that significant protection is afforded to equipment and personnel in the event of an accidental explosion. Slides 16, 17, and 18 show three of the applications of polyurethane barricading. Slide 19 shows a simulated right hand which held a one pint tote in which two grams of NG was detonated by an E-94 blasting cap and a left hand which held a small glass bottle in which 2 grams of NG was detonated.

Although the tote barricade has increased the capacity of our refrigerator storage because propagation will not occur from one tote to another, we have developed two auxiliary storage facilities. One is the mail box storage seen in Slide 20. This unit is designed for 10 grams out-of-door storage. The units are approached from the front in which case operators are not exposed to fragments in the event of an explosion in an adjacent unit.

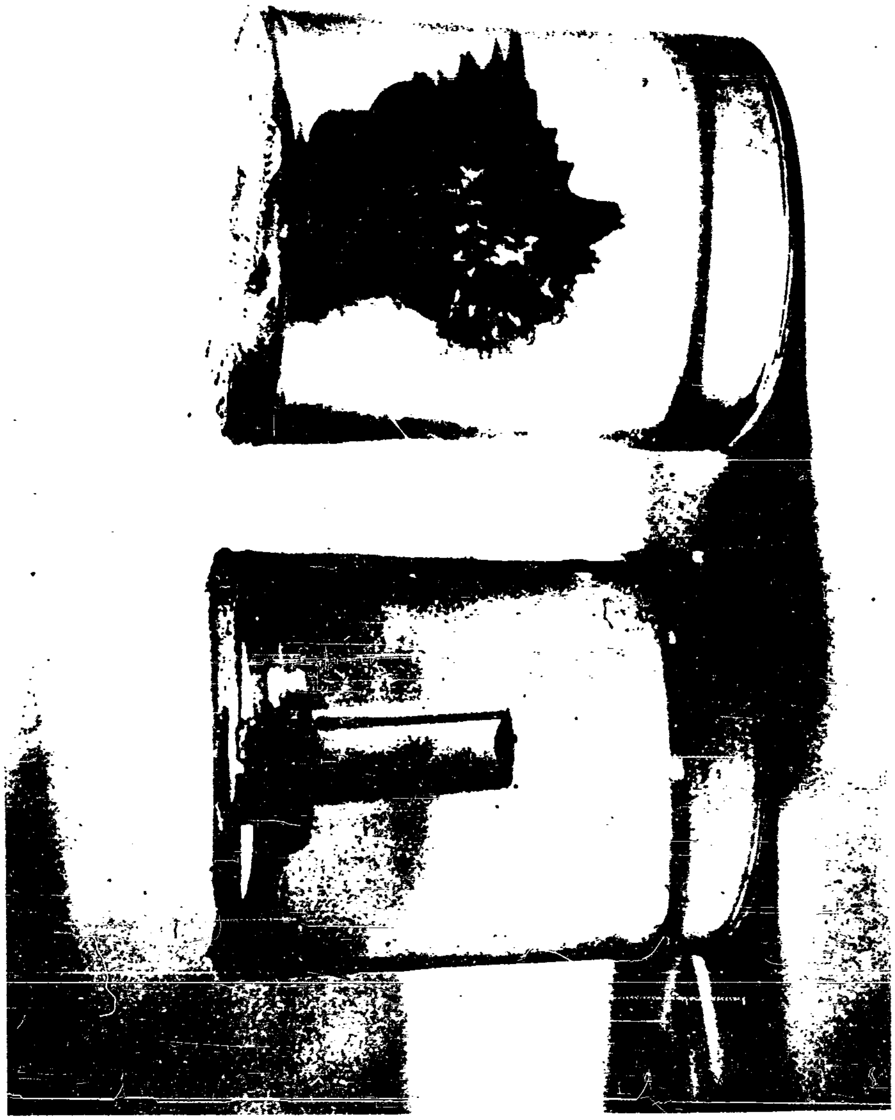
Rohm & Haas and du Pont have cooperated on the development of pipe field storage as shown in Slide 21. The 5' length of 4" Schedule 80 pipe capped on the bottom end is buried 4' in the ground in a vertical position. The pipes are located on 6' centers. Detonation of 1 pound of nitroglycerin in the bottom of one pipe will not propagate to a similar charge in an adjacent pipe. No fragments will be thrown by such a detonation although gas and flame will shoot from the mouth of the pipe.



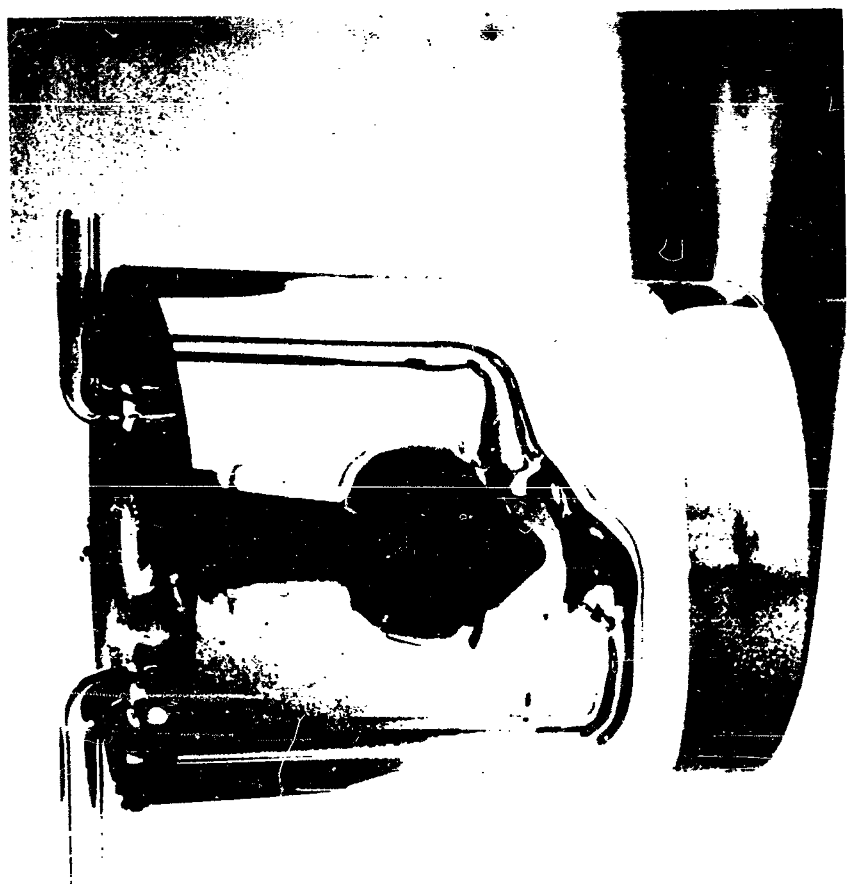
Slide 15-A



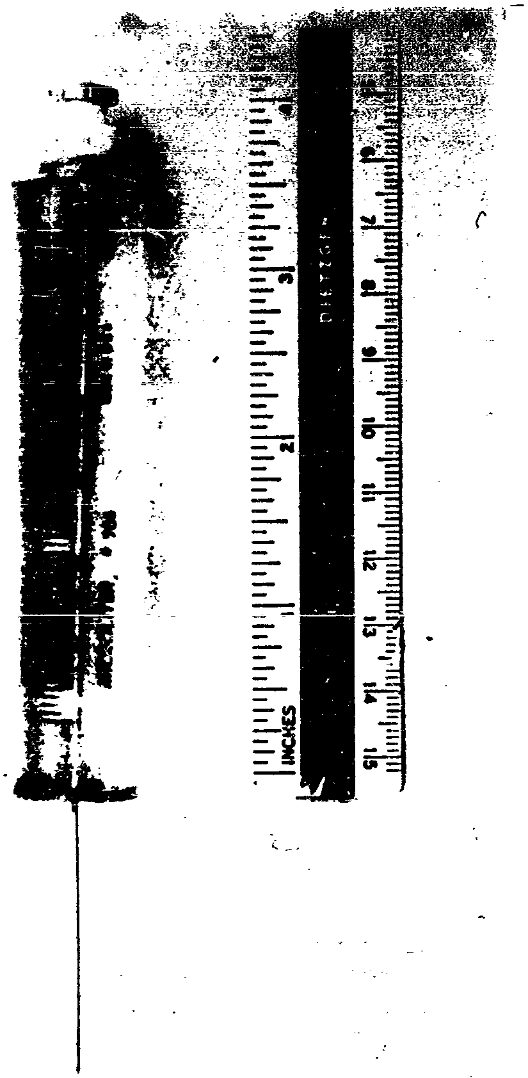
Slide 15-B



Slide 16

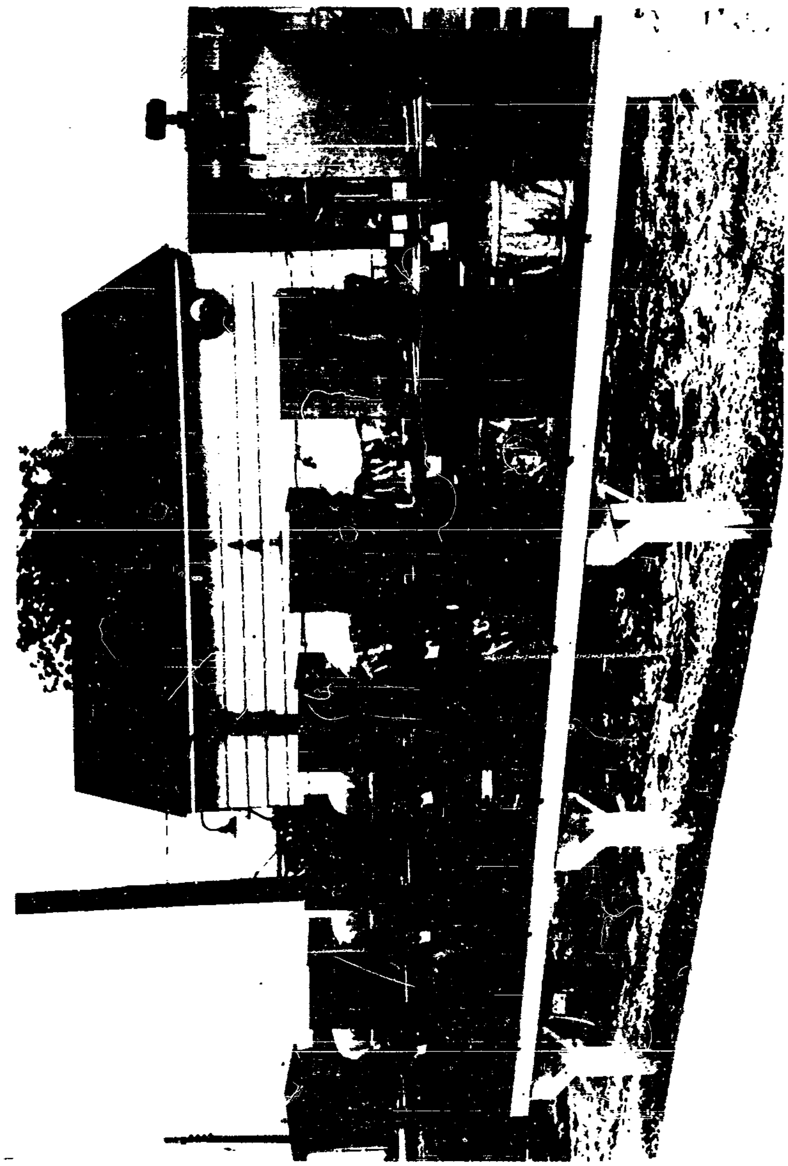


Slide 17



Slide 18

Slide 19



Slide 20

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Slide 21

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A final precautionary statement is in order relative to the use of remote devices and special barricades. Such devices will protect an operator from dismemberment by high pressure gases and injury by missiles, but in general they are not useful in reducing the noise level and its subsequent ear damage. Special precautions must be taken to protect ear drums. Additionally, full consideration must be given to fire and toxicity hazards. Flames from a rapidly deflagrating material can circumvent a shield and injure an operator or initiate a substantial fire and toxic vapors or decomposition gases can find their way out of a hood via cracks and other openings. Such toxic materials may be drawn into the ventilation or air-conditioning system via a ruptured blow-out panel unless care is exercised in the layout.

Mr. Parrette: I would like to dispute your suspicion that there may be a reaction on the operator from an explosion on the operation side of the manipulator. A master slave type manipulator was checked out in this regard in a very expensive experiment by Minn. Mining & Mfg. in which they demolished the whole slave side of the manipulator. A thru-wall type tong was tested by us at the one pound level in a similar manner and in neither instance, rather surprisingly to us, was there evidence that the operator would be injured, possibly bruised, he would get a kick as from a high-powered rifle but at the one pound level, the manipulator would not be driven thru him. Apparently the speed of the detonation and the inertia of the manipulators is a saving grace in this regard.

Mr. Swed: I think we are in agreement here that a man having a manipulator on the side where his arm is free to move would not be injured but I still predict that if a man had a manipulator in front of him and against his breastbone for example, he would sustain a bruise because this thing comes out at a rather high velocity.

Mr. Scott: I have two questions regarding the hood you rated at 25 grams. First, is this rating associated with a specified minimum distance that must be maintained between the energetic material and the front face walls and bottom and second, if so do you use any physical barrier or visible warning device to assist the operator in maintaining such distances?

Mr. Swed: The test was 12" and this is the distance we maintain, we try to line our materials up in the back of the hood, we do not have any warning devices relative to moving the material toward the front of the hood. We do, however, have warning lines on the floor in the laboratory to indicate that people should not approach the hood without earmuffs, for example. This might be a consideration we might make relative to the 12" limit.

Col. Hamilton: Gentlemen, as a lot of you know, the Armed Services Explosives Safety Board is a joint board and approximately every two years the Chairmanship rotates from one Service to the next. At the end of this month, I'm retiring and the Chairmanship rotates to the Air Force. I can't think of any better way for you fellows to get to know the new Chairman designate than for him to act as Moderator for the rest of this meeting and that will permit me to sit back and take it easy a little bit. I'd like to introduce Col. McCants who is scheduled to be the next Chairman.

Col. McCants: Thank you very much Col. Hamilton.

MINIMIZING INITIATION HAZARDS THROUGH PROPER SELECTION OF MATERIALS OF FABRICATION

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INTRODUCTION

With the advent of more sensitive ingredients, new processes and new materials of fabrication in the manufacture of rocket motors, it has become mandatory to seek various means of minimizing the possible hazards associated with the introduction of these advances. As one means of accomplishing this, a sensitivity investigation has been conducted which employs test components fabricated of both conventional and experimental materials of fabrication.

It would be well to define the term "materials of fabrication" in connection with its use in this presentation. We are concerned with those materials from which machinery, containers, tools, floors, etc.,are made and which could present impact and friction surfaces in the processing areas. For the purpose of this discussion, consideration is not given to the materials employed in building walls, doors or barricades for air blast protection.

Materials selected for use in this study were those (1) most commonly used in the process, (2) possessing a lower modulus of compression or coefficient of friction or (3) contemplated for replacement parts or for use in new design. The situations considered and data generated by the above investigations are voluminous and sometimes of a specialized nature; therefore, only typical examples of the subject are presented.

The purpose of the investigation was threefold:

1. to find materials of fabrication for which an increased level of input energy is required to initiate combustibles, using impact and friction sensitivity results as the screening criteria.

2. to establish the limitations of a material's use by observation of its physical performance during the above tests and through consideration of its physical characteristics (i.e., structural properties, dimensional stability, thermal and electrical conductivity, hardness and coefficient of friction).

3. to use the above information in conjunction with an engineering analysis and, with simulated testing as required, for a specific application.

This report has several purposes: (1) to demonstrate the safety advantages of using specific materials of fabrication, (2) to examine the reasons for the observed effects of these materials on the initiation of combustibles, (3) to cite typical applications for such materials, and (4) to identify the factors which must be considered in their selection.

EXPERIMENTAL

The impact and friction data were obtained using the test apparatus shown in Figures 1 and 2. The operating principle of each device can be seen in Figure 3

Basically the impact apparatus is comprised of a falling weight which is used to impact a small amount of sample between two impacting components such as the hammer insert (nominally 0.2 in^2) and anvil shown in Figure 3. Thus one can subject samples to varying degrees of impact energy by varying the drop height or weight.

In the friction apparatus, a given sample is placed on the sliding anvil and a force is applied to the sample by a stationary wheel (0.1" thick x 2" OD) attached to a hydraulic ram. A 26-pound pendulum is dropped from a selected height to strike the anvil with sufficient energy to slide the anvil perpendicular to the normal force at a nominal initial velocity of 8 ft/sec.

For this investigation and depending on the situation being studied, various materials were used in the hammer insert or stationary wheel and anvils. The friction apparatus also provided the kinetic coefficients of friction given herein.

The data obtained from both apparatus are given as the threshold initiation level (TIL). TIL is defined as the test level at which twenty consecutive trials result in "failures" (no initiation), with at least one "shot" (initiation) occurring at the next higher test level. The impact and friction threshold levels are given in terms of ft-lb/in^2 and lbs-force, respectively.

Hardness, modulus of compression and surface finish values were established by the following techniques: Rockwell and Durometer devices, hardness; ASTM-D-695-54, modulus of compression; and Brush Electronics Company "Surfindicator" instrument, surface finish.

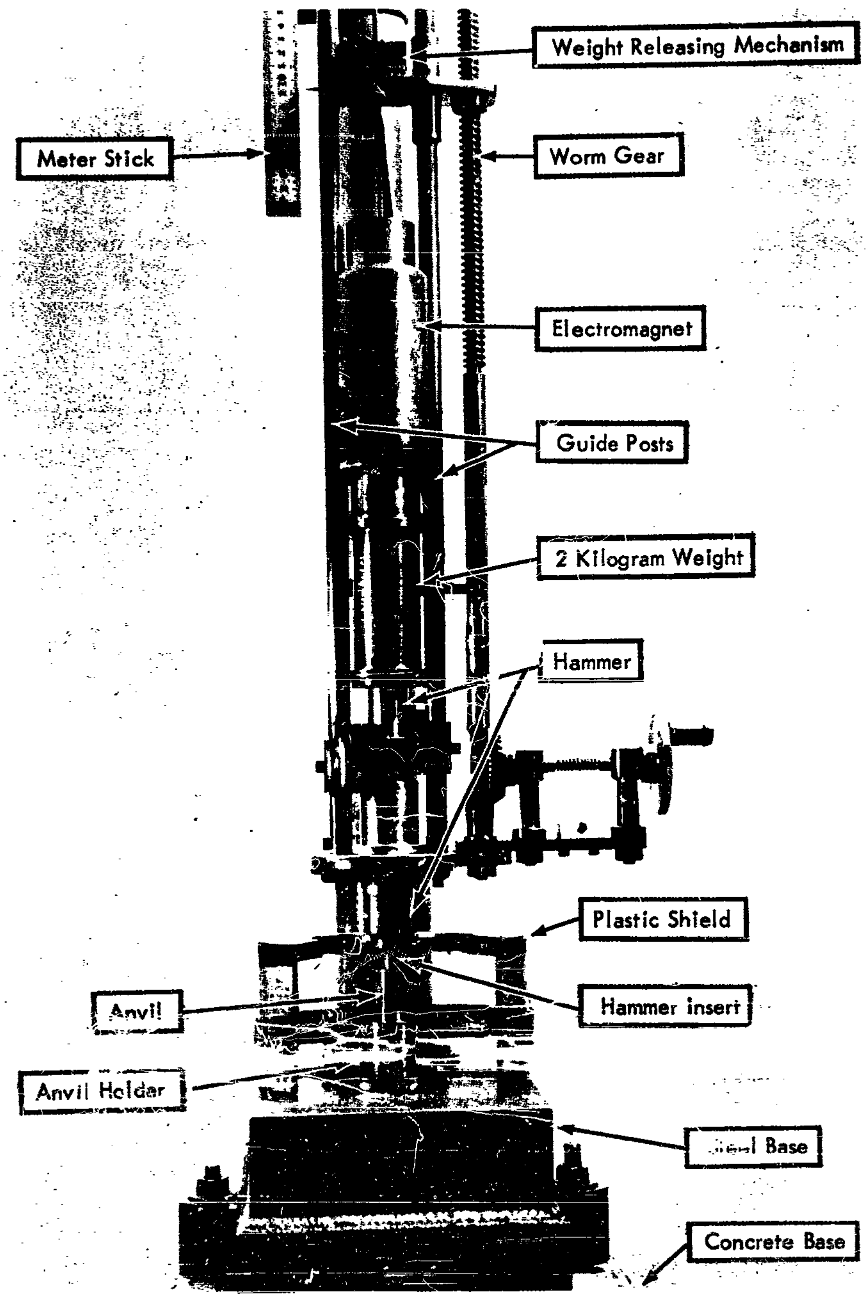

FIGURE 1

ABL Impact Sensitivity Testing Machine

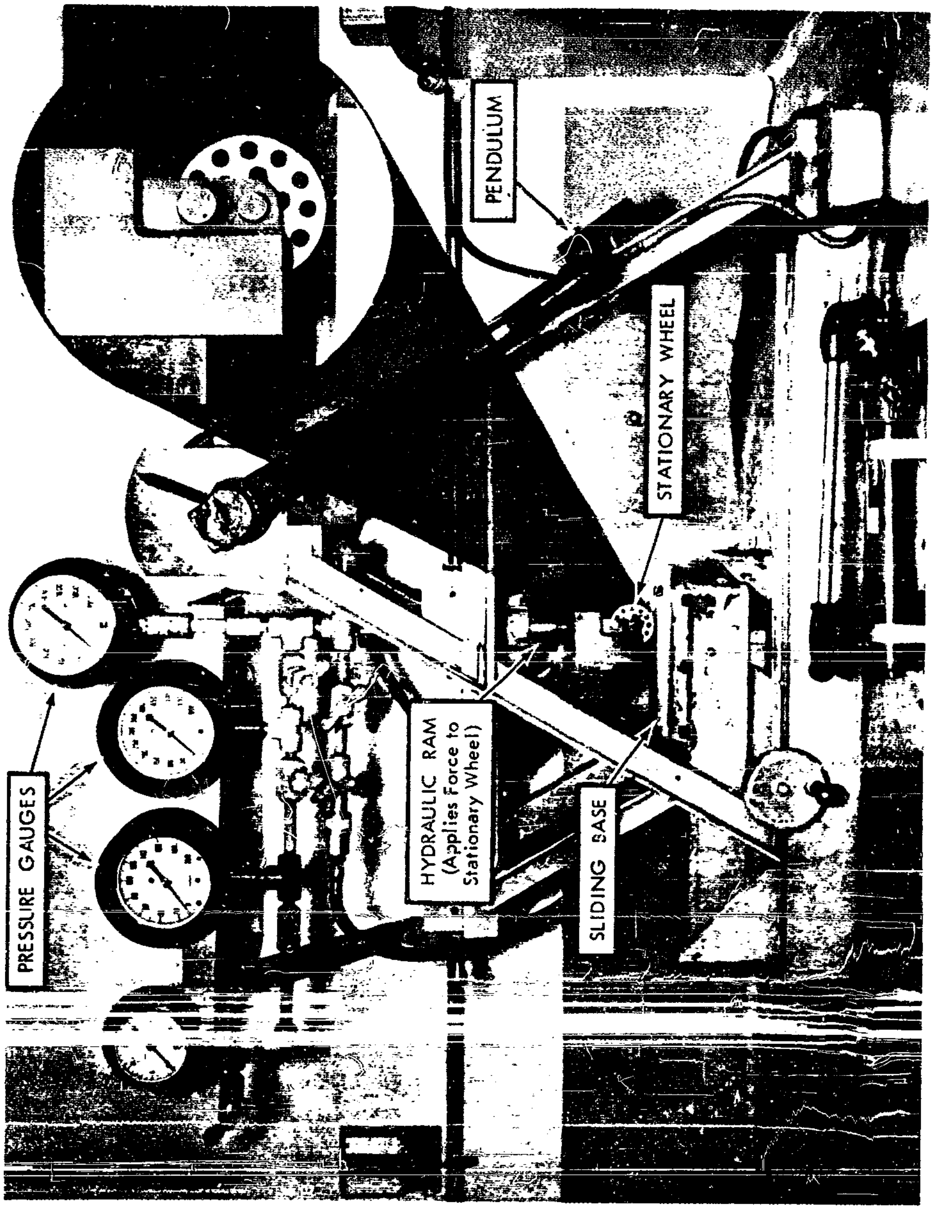

FIGURE 2

ABL Sliding Friction Machine

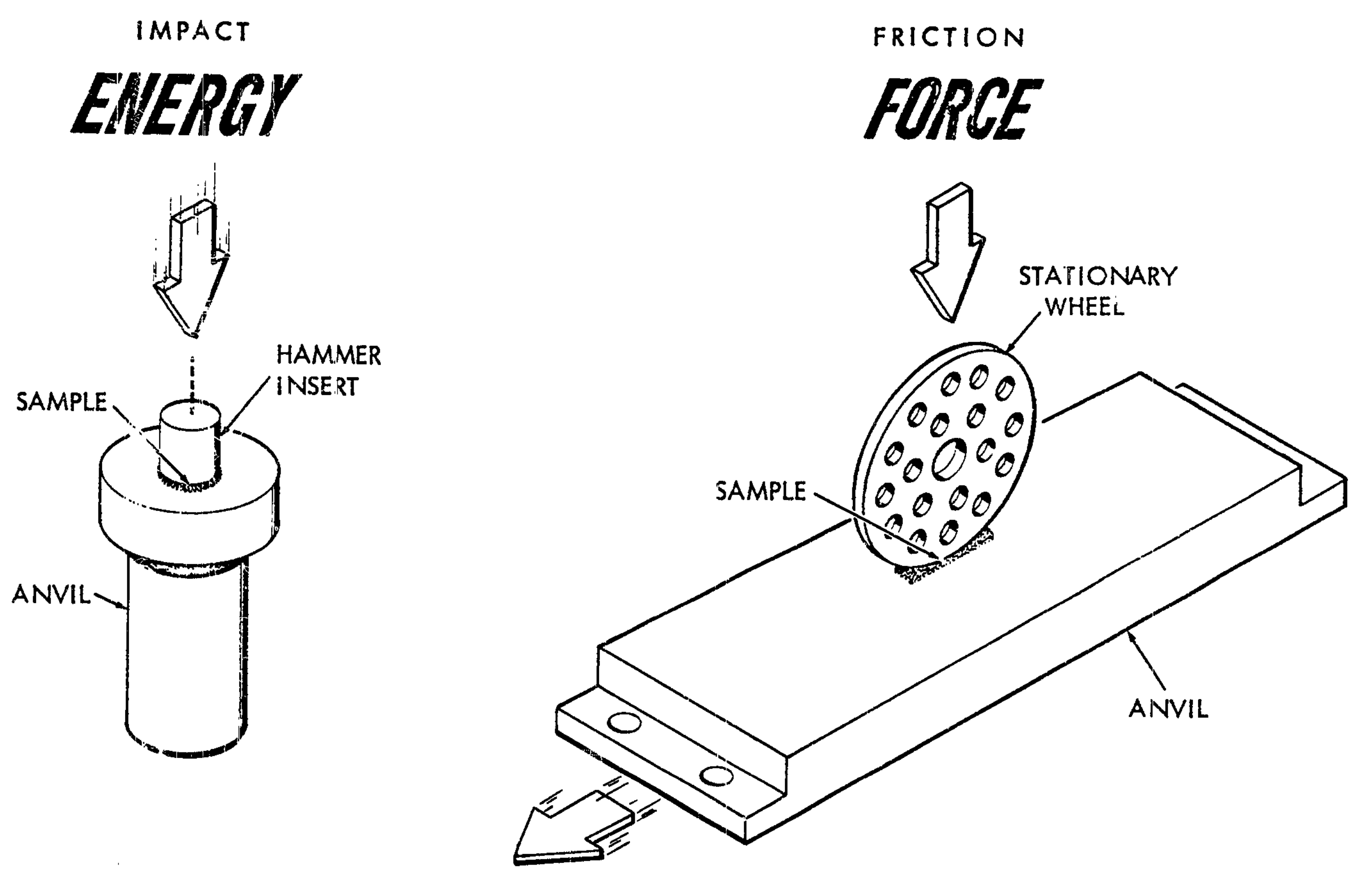

FIGURE 3
Operating Principle of Impact and Friction Test Apparatus

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RESULTS AND PHYSICAL CHARACTERISTICS

Of the 43 combinations of materials tested thus far, seven combinations are shown in Table I for which impact and friction data are available using a single type of combustible. This table reveals two noteworthy items.

1. Significant increases in the level of input energy required for initiation can be achieved by proper selection of materials, e.g., SS/SS vs. SS/Hi-fax. *

2. Not all materials significantly influence in the same direction both the impact and friction input energy required for initiation, e.g., SS/SS vs. TSS/TSS. * Small changes in input energy such as 2 to 6 ft-lbs/in^2 for SS/SS vs. SS/concrete are not considered significant as they are within the range of values that could be expected because of test variation.

The characteristics showing the most significant influence on impact data appear to be the ability of the material to compress readily and the hardness of the material. The gross effect can be seen in Table II by comparing SS/SS and wood/lead test data where the modulus of compression and relative hardness of both test components are either high or low. The modulus of compression is used here as an indication of the compression properties of a material. The substitution of one component with a low modulus of compression also increases TIL (see Table II), although generally less than when both components possess low moduli of compression.

Sufficient information is not available to afford a discussion of the interactions of the various factors influencing friction data previously shown in Table I. However, it would appear reasonable to assume that hardness and coefficient of friction are two important factors. Current information indicates that the coefficient of friction of materials of fabrication significantly influences TIL of solid and liquid combustibles (Table III). It is noteworthy that coefficient of friction determinations with combustibles between the components show that solids can act as a lubricant, reducing the coefficient of friction by as much as a factor of three, whereas no effect is apparent with liquids. This effect of solids on coefficient of friction is to be expected when the thin layer of solid has a lower shear strength than that of the test components.[1] This is further substantiated by the TSS/TSS data which show that this effect is nullified by the presence of a material having a lower shear strength than the combustible, such as, Teflon.

The effect of surface finish between the limits of 8 and 190 microinch on stainless steel was considered; and improvement was noted in the friction TIL with the smoother finishes (Table IV). Impact results are essentially unaffected by such variations of surface finish based on previous data on solids[2] and current data on NG. The force data for nitroglycerin are shown at 3 ft/sec to facilitate comparison.

*See Glossary

TABLE I

TYPICAL EFFECT OF MATERIALS OF FABRICATION

Components Hammer or Wheel/Anvil	Nitroglycerin (TIL) Impact (ft-lbs/in^2)	Nitroglycerin (TIL) Friction (lbs-force)
SS/SS*	2.0	< 1
SS/Concrete	6.0	< 1
TSS/TSS	4.0	> 900
SS/A1	3.0	> 100
SS/Lead	13.0	> 150
A1/Wood	45.0	> 150
SS/Hi-fax	60.0	> 360

* See Glossary for meaning of abbreviations

TABLE II

EFFECT OF MODULUS OF COMPRESSION AND HARDNESS ON IMPACT TIL

Type of Component Hammer/ Anvil	Modulus of Compression psi x 10^4 Hammer/Anvil	Relative 1/ Hardness	Nitroglycerin (TIL) (ft-lbs/in^2)
SS/SS	8700/8700	Hard/Hard	2.0
SS/Lead	8700/27	Hard/Soft	13.0
PE/SS	2/8700	Soft/Hard	25.0
Wood/Lead	82/27	Soft/Soft	>85

1/ Hard - Rockwell "B" - 80 through "C" - 60.

Medium - Rockwell "H" - 10 through "B" - 79.

Soft = < Rockwell "H" - 10.

TABLE III

EFFECT OF COEFFICIENT OF FRICTION ON FRICTION TIL

Components Wheel/Anvil	Kinetic Coefficient of Friction Without Sample	Combustible Sample	Kinetic Coefficient of Friction With Sample	Friction Sensitivity Threshold Initiation Level (lbs-force)
SS/SS	0.48	Nitroglycerin	0.47	<1
		CMDB Propellant*	0.14	160
TSS/TSS	0.05	Nitroglycerin	0.05	> 900
		CMDB Propellant	0.05	840

* CMDB propellant was tested in a ground state resulting in a particle size approximating 0."025 x 0."025.

TABLE IV

EFFECT OF SURFACE FINISH ON IMPACT AND FRICTION TIL

Surface Finish (microinch)	Impact ($ft-lbs/in^2$) Nitroglycerin	Friction (lbs-force) Nitroglycerin	Friction (lbs-force) CMDB Propellant
Rough (190 microinch)	4	4 at 3 ft/sec.	< 1 at 8 ft/sec
Medium (60 microinch)	2	20 at 3 ft/sec	160 at 8 ft/sec
Smooth (8 microinch)	4	>60 at 3 ft/sec	280 at 8 ft/sec

APPLICATIONS AND INFLUENCING FACTORS

The ultimate purpose of this work is to aid in the selection of materials of fabrication which will increase safety in the propellant manufacturing process. This requires that each application be considered on its own merit and, more importantly, that the selection of a material to reduce sensitivity in one area does not introduce a new hazard by increased sensitivity in another area. To explore all sensitivity areas requires consideration of factors such as thermal and electrical conductivity, structural strength, load bearing characterisitics and dimensional stability as well as the effect on impact and friction input energy.

For the purpose of this discussion, polyethylene (generally Hi-fax) and Teflon will be used as examples since they typify materials which can be employed to improve impact and friction hazards and yet are unique for specific applications.

In general they are employed as seals, gaskets, mats, bumpers, linings, scrapers, coatings, containers, guards, collars, nozzles and corsets. Some specific applications are as follows:

1. Submerged Teflon glands in mixers (Figure 4) - Replacement of a metal seal with one made of Teflon results in a significant contribution to the safety of the mixing operation, particularly when oxidizers such as ammonium perchlorate are used. The use of Teflon provides a low coefficient of friction and a compressible, soft material should undue force be applied through excessive shaft deflection.

2. Hi-fax inserts (Figure 5) - The purpose of the insert is to eliminate metal to metal contact between the mold core and associated parts during transportation and core removal. Hi-fax inserts were used in this particular application because the integrity of Teflon coatings or similar types of thin coatings could not be relied upon under conditions of high localized forces and because, as pointed out earlier, such coatings do not provide any significant impact advantage. The use of Hi-fax inserts is relatively inexpensive as compared to some other materials, particularly coatings, which require frequent rework. The above application is an example of the use of a compressible, soft material with a low coefficient of friction where complete substitution of the material was not desirable for reasons of structural strength and dimensional stability.

3. Hi-fax fin cores (Figure 6) - Hi-fax was best suited as material for fin cores because its physical form and its placement in the mold provided good dimensional tolerance, and because Hi-fax was structurally acceptable, economical, and reduced the potential impact and friction hazards during mold handling and fin removal.

4. Hi-fax gaskets and bumpers (Figure 7) - Hi-fax was employed in a hydraulic press to provide a cushioning effect for the reduction of impact hazards and to eliminate metal to metal contact.

The foregoing has discussed some specific applications of Teflon and polyethylene (Hi-fax) demonstrating their varied advantages. Some limitations in the use of these materials are shown by the following examples:

1. Polyethylene as a material of fabrication to minimize impact hazards - Because polyethylene is a relatively soft, compressible material, it is generally conceded to be useful for applications where some means is required to absorb some or all of the impact which might occur in propellant processing. A factor to be considered in selecting the proper thickness of material is the mass of the impacting object. This can be demonstrated by referring to Figure 8 which shows the increase in impact TIL as a function of increasing thickness of polyethylene for a constant mass drop weight (2.2 lbs.). This figure also shows that representative solid and liquid combustibles react differently to varying thickness. Figure 9 shows that the effect of thickness is dependent to varying degrees on the mass of the drop weight. The nitroglycerin data indicate that the use of compressible materials under process conditions of heavy impacting masses may not improve the impact hazard significantly. The solid combustible (CMDB propellant) data indicate there may be a critical effective thickness (>0.03 <0.09 inch) of polyethylene insofar as the impacting mass is concerned.

   Thus, when consideration is given to the use of polyethylene or any similar material to reduce impact hazards, the thickness must be established as a function of the impacting mass. Representative combustibles in the form of test samples may be employed as guides. However, in the final analysis the specific combustible must be considered.

2. The use of Teflon as a material of fabrication for a vacuum seal in high speed mixing (200-500 rpm) (Figure 10) - The principle of the design was to allow lateral displacement of the mixer shaft and still provide a vacuum seal. Teflon was selected on the basis of its low coefficient of friction.

   Analysis of this application revealed that under conditions of absolute vacuum the seal could be subjected to a vertical 64 lbs. force and that this force could be delivered over as small an area as 0.1 in^2. Since it was reasonable to assume that this area, as well as the ball and socket joint, could become contaminated with combustibles, impact, friction and simulated operational tests were performed. The more pertinent results were as follows:

(a) It was found that Teflon was not structurally adequate as the bearing plate under the forces involved.

(b) Teflon could gall in the ball and socket joint because of high temperatures generated at normal mixer speeds (400 rpm). Temperature measurements showed that Teflon apparently reached its heat distortion temperature which is given in Reference 3 as 266°F.

(c) Initiation of combustibles was likely even at speeds lower than those contemplated for normal operation (400 rpm).

(d) Initiation was the result of both the frictional energy created and the gross temperature increase resulting from the heat generated by the Teflon components. It is noteworthy that the friction test does not consider the latter condition, and prior analysis of the situation; based on friction results alone; did not predict initiation for many of the combustibles tested.

(e) The use of air as a coolant and vacuum grease to reduce the frictional and heat generation hazards was inadequate.

(f) Although Teflon is an excellent dielectric material, no electrostatic charges were detected under the conditions of its intended use.

In the vacuum seal application Teflon has several limitations. It was structurally inadequate, its thermal conductivity was too low, and its very good coefficient of friction was overshadowed by other considerations.

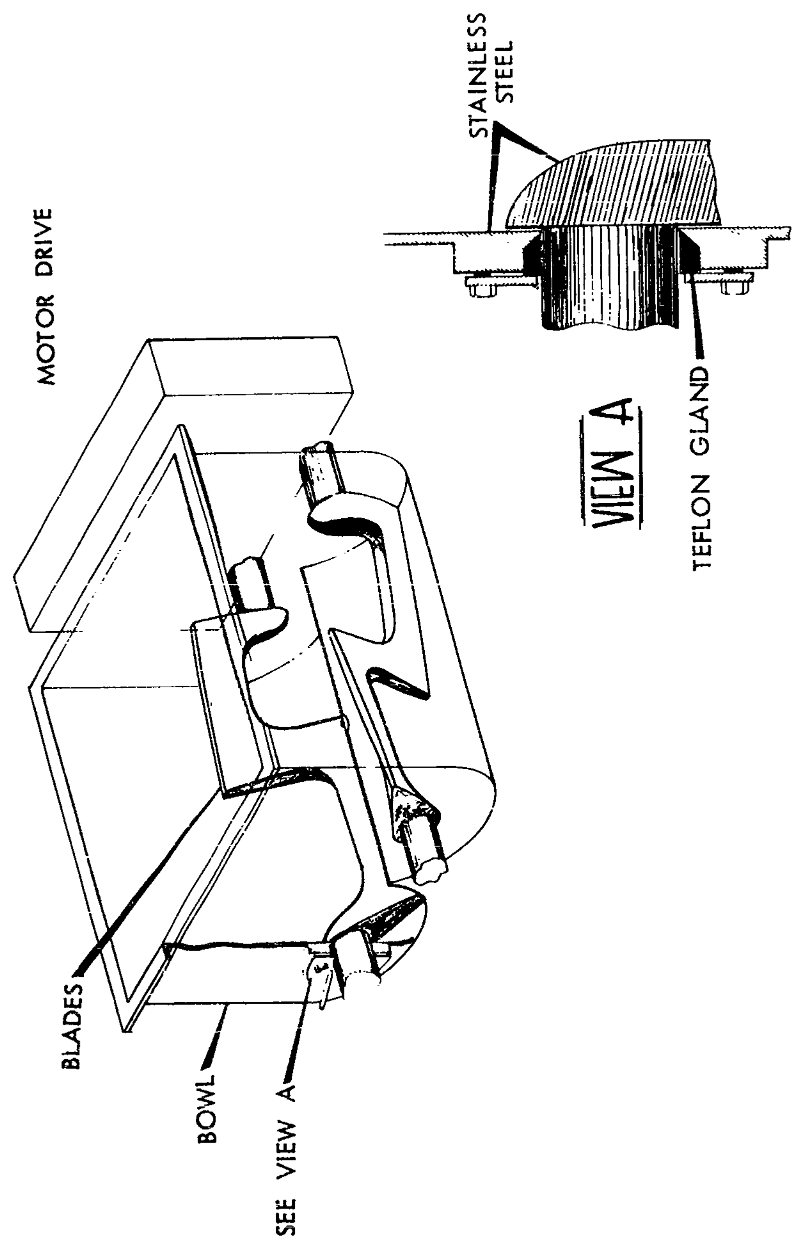

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FIGURE 4
Horizontal Sigma Mixer

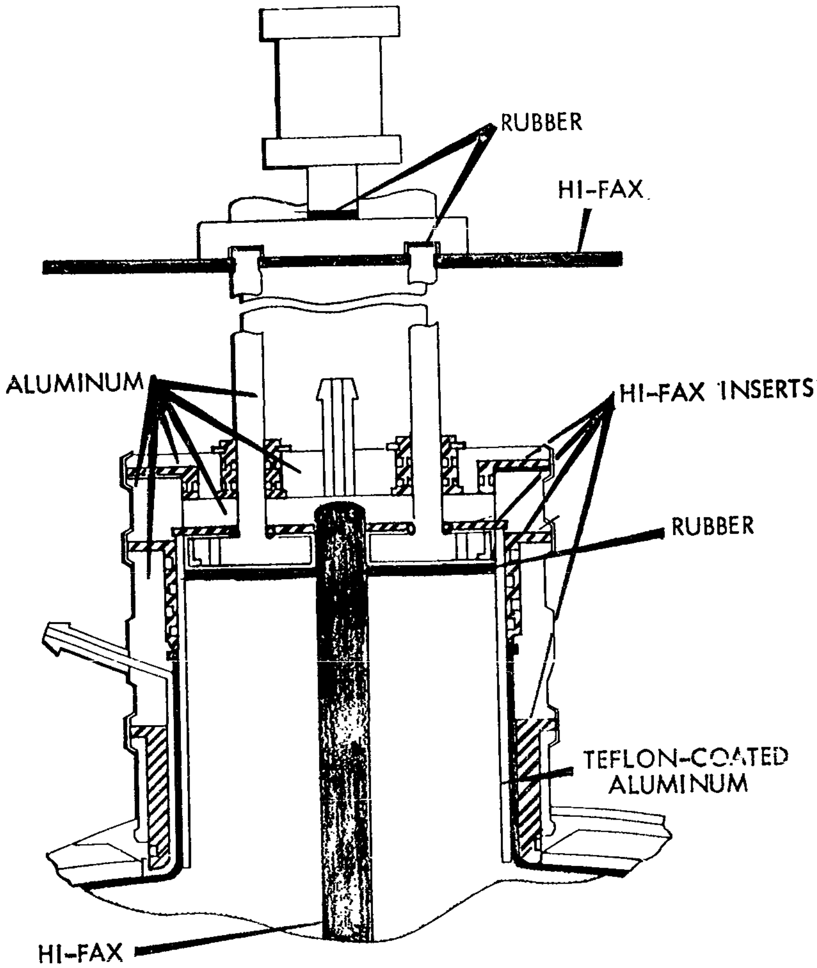

FIGURE 5
Casting Assembly

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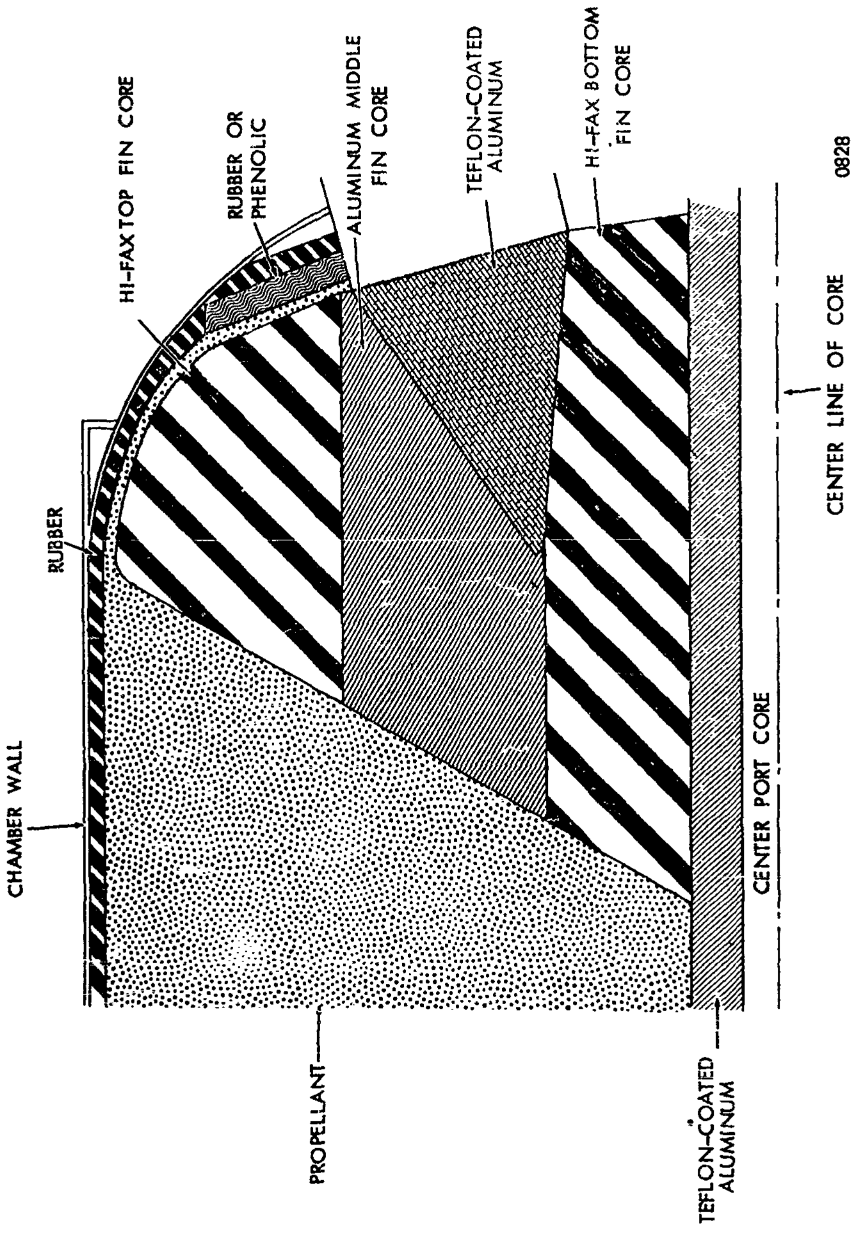

FIGURE 6
Mold Core Arrangement

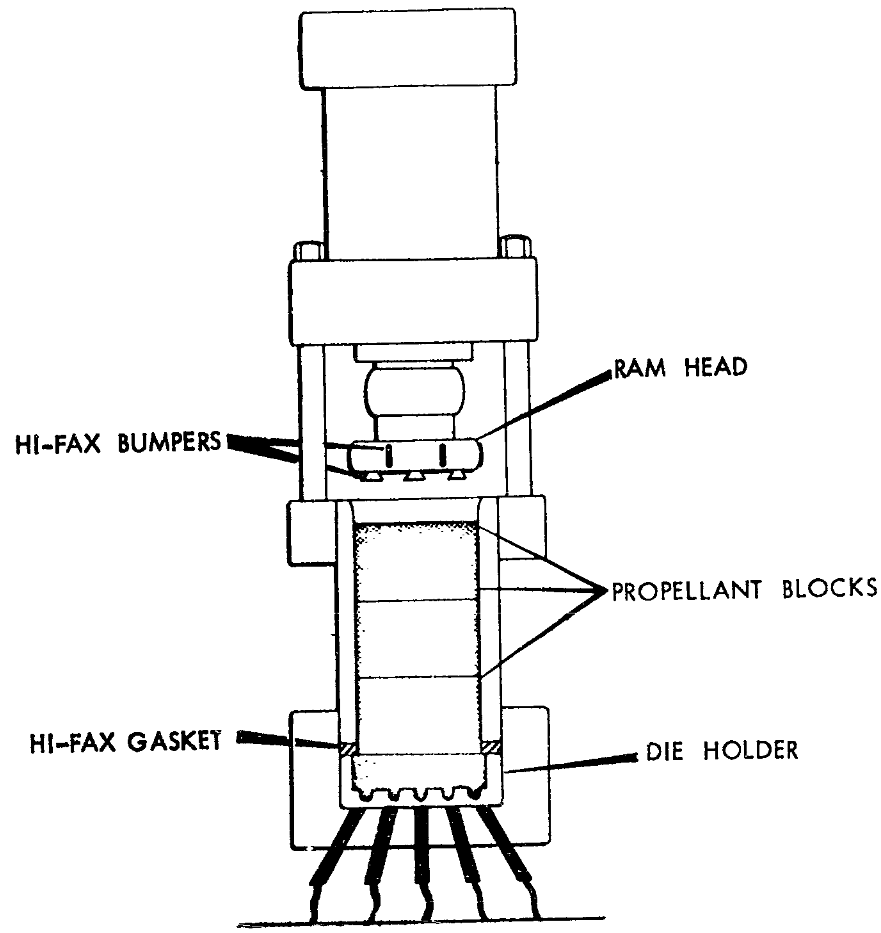

FIGURE 7
Pressing Operation

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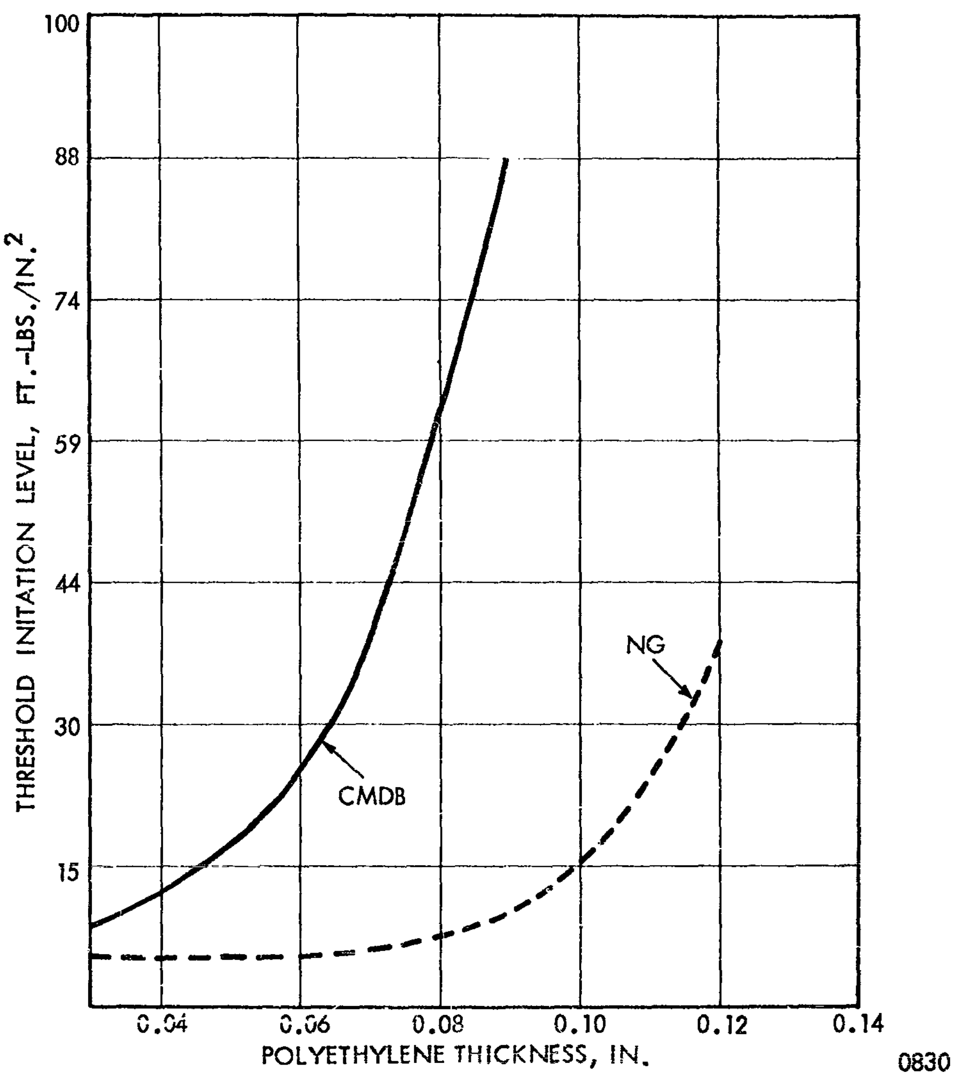

FIGURE 8
Impact Threshold Initiation Level Vs. Polyethylene Anvil Thickness

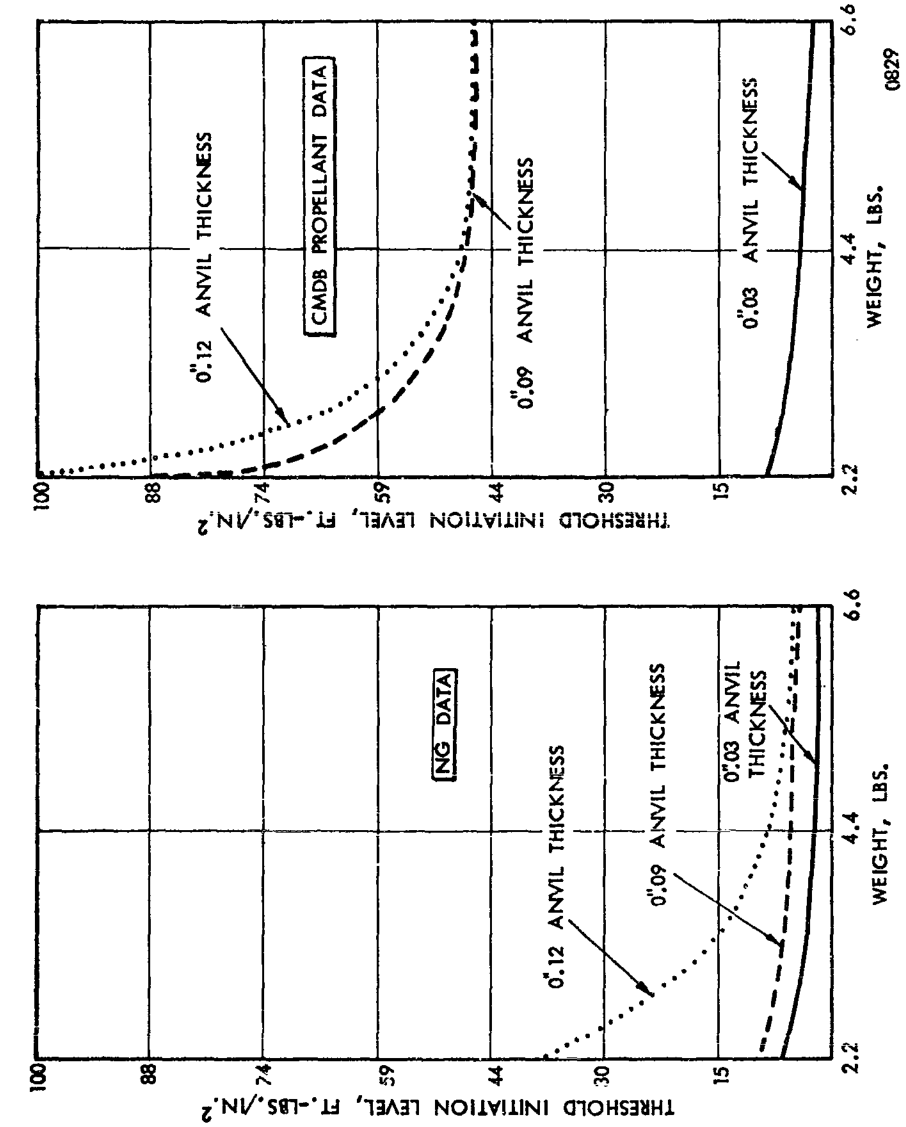

FIGURE 9
Impact Threshold Initiation Level Vs. Weight of Impacting Mass

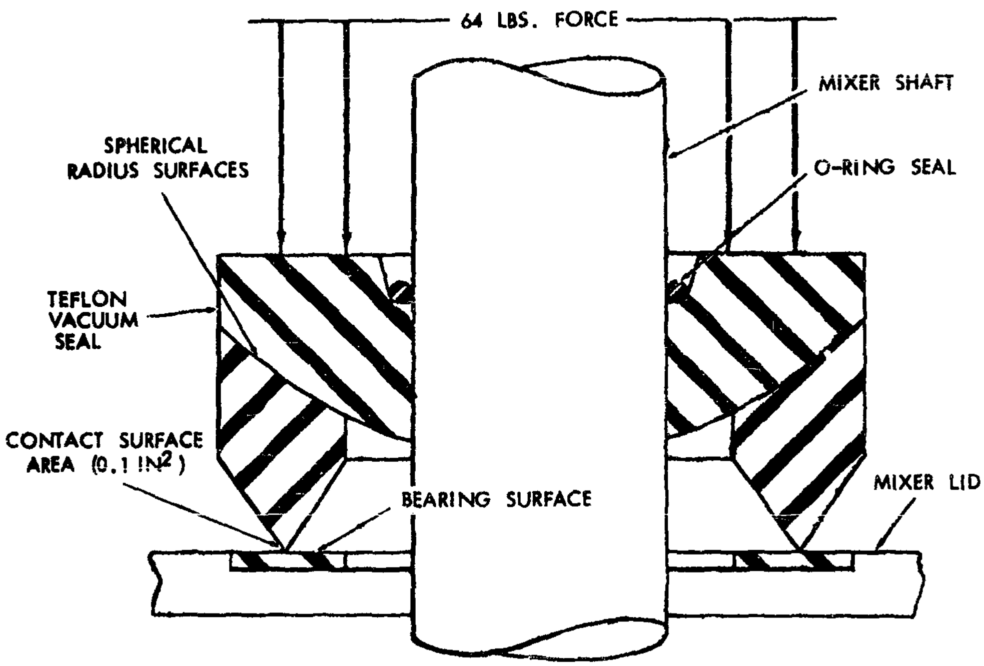

FIGURE 10 0814
Schematic Drawing of Self-Positioning Teflon Vacuum Seal for High Speed Mixing

GLOSSARY

ABL	Allegany Ballistics Laboratory
Al	Aluminum
CMDB Propellant	Composite Modified Double-Base Propellant
Hi-fax	Hercules Powder Company trade name for densified polyethylene
NG	Nitroglycerin
PE	Polyethylene
SS	Stainless Steel
Teflon	E. I. duPont de Nemours & Company trade name for tetrafluroethylene
TSS	Teflon-coated stainless steel, nominally 0.001 inch thick
TIL	Threshold initiation level
$\geq$	The symbol means that initiation of the test sample was not obtained in twenty trials (1) at the highest level on the impact apparatus and (2) the highest level on the friction apparatus that would consistently allow the slider to move the standard one inch or that at greater forces would damage the wheels and/or anvils.

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COMPARISON OF EFFECTIVENESS OF SANDWICH-TYPE CONSTRUCTION AND STANDARD REINFORCED CONCRETE CONSTRUCTION FOR PROTECTIVE WALLS

by
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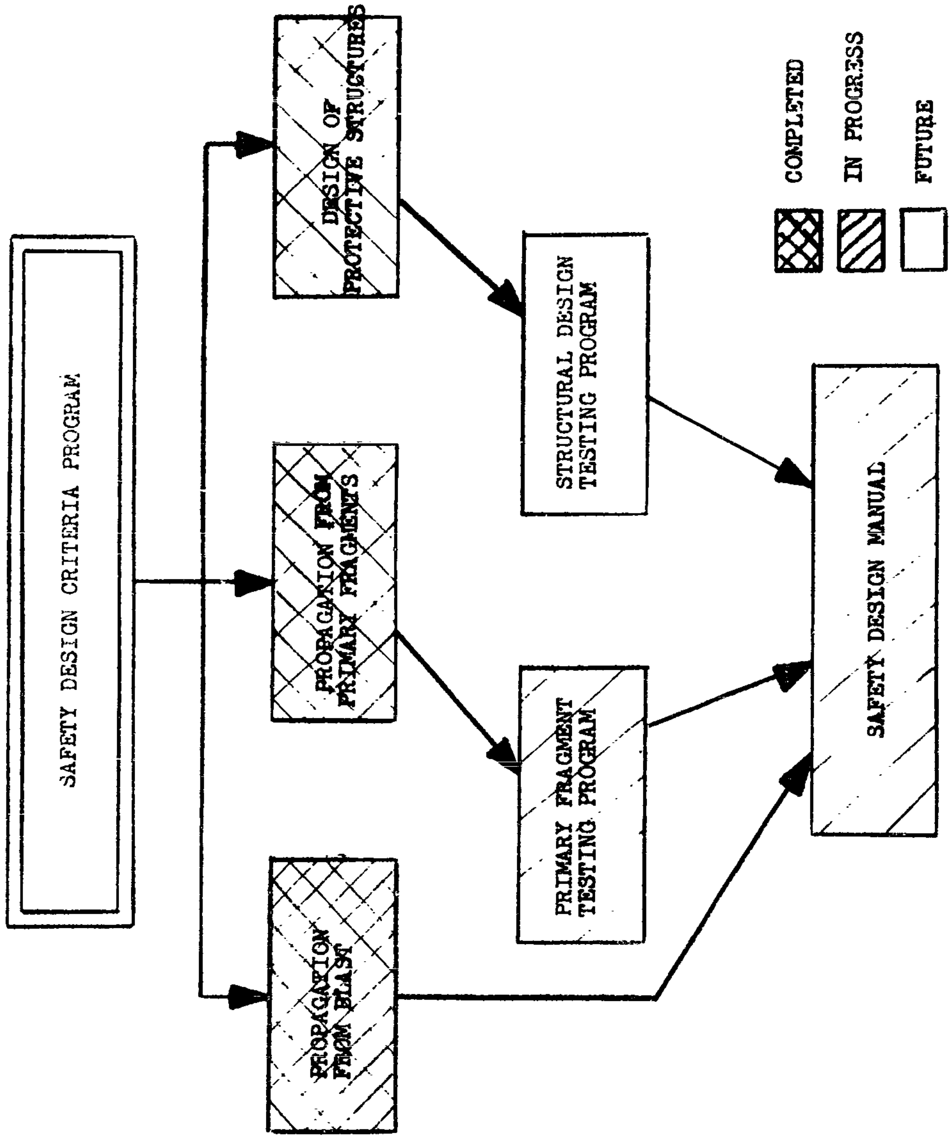
Various phases of the Picatinny Arsenal safety design criteria program have been discussed at the three previous Safety Seminars. For purposes of a very quick review let us look at Slide 1 which schematically outlines the various phases and status of our overall program. All the analytical phases of this work, including the most complex structural design phase, have now been essentially completed. We have developed detailed design relationships which represent a major step forward toward permitting a systematic, quantitative approach to the solution of virtually any problem relating to protection against propagation of explosions, personnel injury and materiel damage. This is of particular significance in the light of today's high energy propellant systems with attendant problems of designing safe, economical manufacturing plants, missile storage facilities and launching sites. Let me emphasize at this point, that although the design relationships developed, are based upon very extensive correlation of a very great amount of actual data as well as theoretical approaches, these relationships must be specifically confirmed by actual tests before they can be reliably applied. As indicated on the chart, a portion of these tests is currently in progress. We are also just getting underway with a model scale test program to confirm the analytically developed structural design relationships.

Let us now consider, generally, the various possible locations of an explosive charge (i.e. a potential explosion) relative to a protective wall, as shown on Slide 2. First, we may have situation where the charge is

SLIDE 1


SAFETY DESIGN CRITERIA PROGRAM
DESIGN OF PROTECTIVE STRUCTURES
PROPAGATION FROM PRIMARY FRAGMENTS
PROPAGATION FROM BLAST
STRUCTURAL DESIGN TESTING PROGRAM
PRIMARY FRAGMENT TESTING PROGRAM
SAFETY DESIGN MANUAL
COMPLETED
IN PROGRESS
FUTURE

SLIDE 2

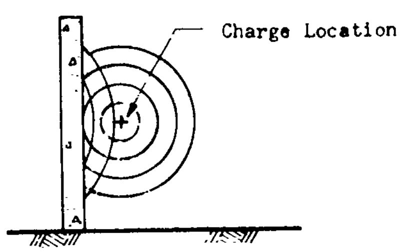


Fig. 2.2a FREE AIR

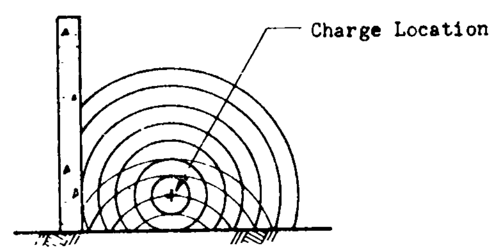


Fig. 2.2b PART FREE AIR AND PART REFLECTED

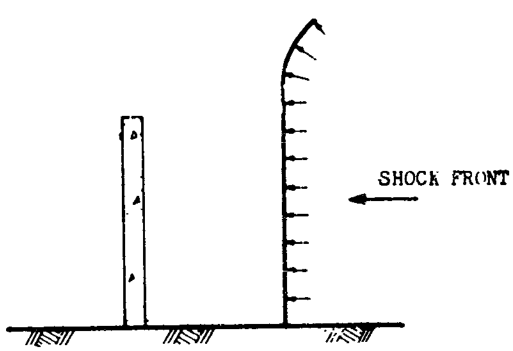
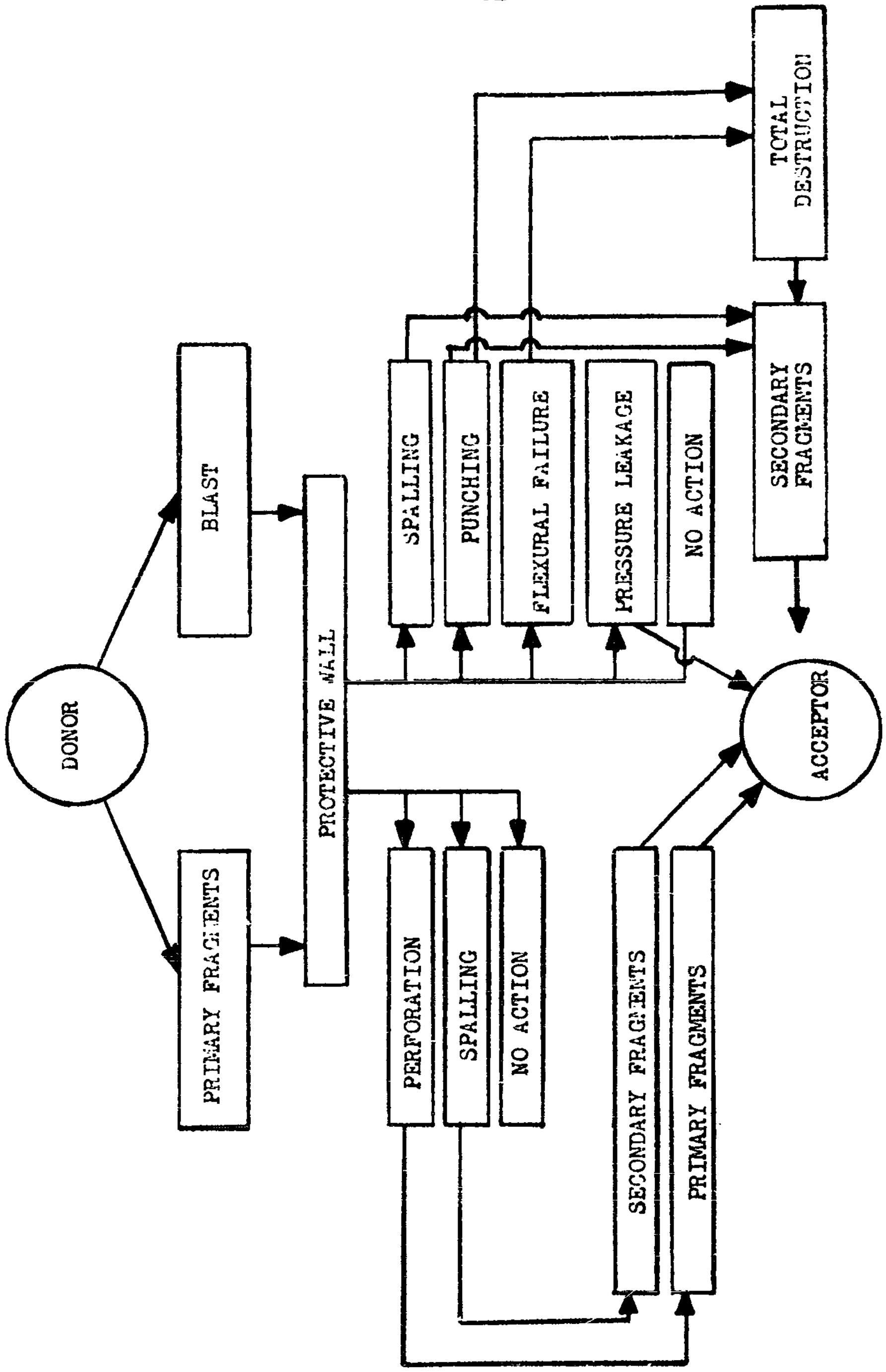


Fig. 2.2c PLANE SHOCK WAVE

located close to the wall but sufficiently high above ground level, so that the wall is subjected essentially to a free air blast effect. Secondly, the charge may again be located relatively close to the wall, but also close to ground level, so that the wall is subjected to a combination of free air blast and ground reflection effects. In both of these cases, the wall is subjected to a non-uniform loading over its surface, with concentration of blast effects in the general area normal or almost normal to the charge. The third possibility is location of the charge far enough away from the wall so that the wall is subjected to a plane shock wave, i.e. uniform blast loading over its entire surface.

In most cases of ordnance interest (e.g. operating bays, storage cubicles), explosive charges will be located close to the protective wall and probably close to ground level. Our analytical work indicated that it is under these conditions that most severe damage to the wall occurs, not only for the obvious reason of charge proximity, but also because of intense effects resulting specifically from the non-uniform wall loading (e.g. punching out of very large concrete masses having substantial velocities). Slide 3 summarizes the various possible modes of wall failure. By way of confirmation, results of large scale tests recently conducted by the Armed Services Explosives Safety Board have strongly demonstrated that, for close-in effects, the degree of protection afforded by standard reinforced concrete walls in thicknesses up to several feet is far below what might previously have been expected based on, for example, plane wave theory. As a matter of fact, it may be said, based on these large scale tests, that standard reinforced concrete walls

SLIDE 3



DESIGN OF PROTECTIVE STRUCTURES

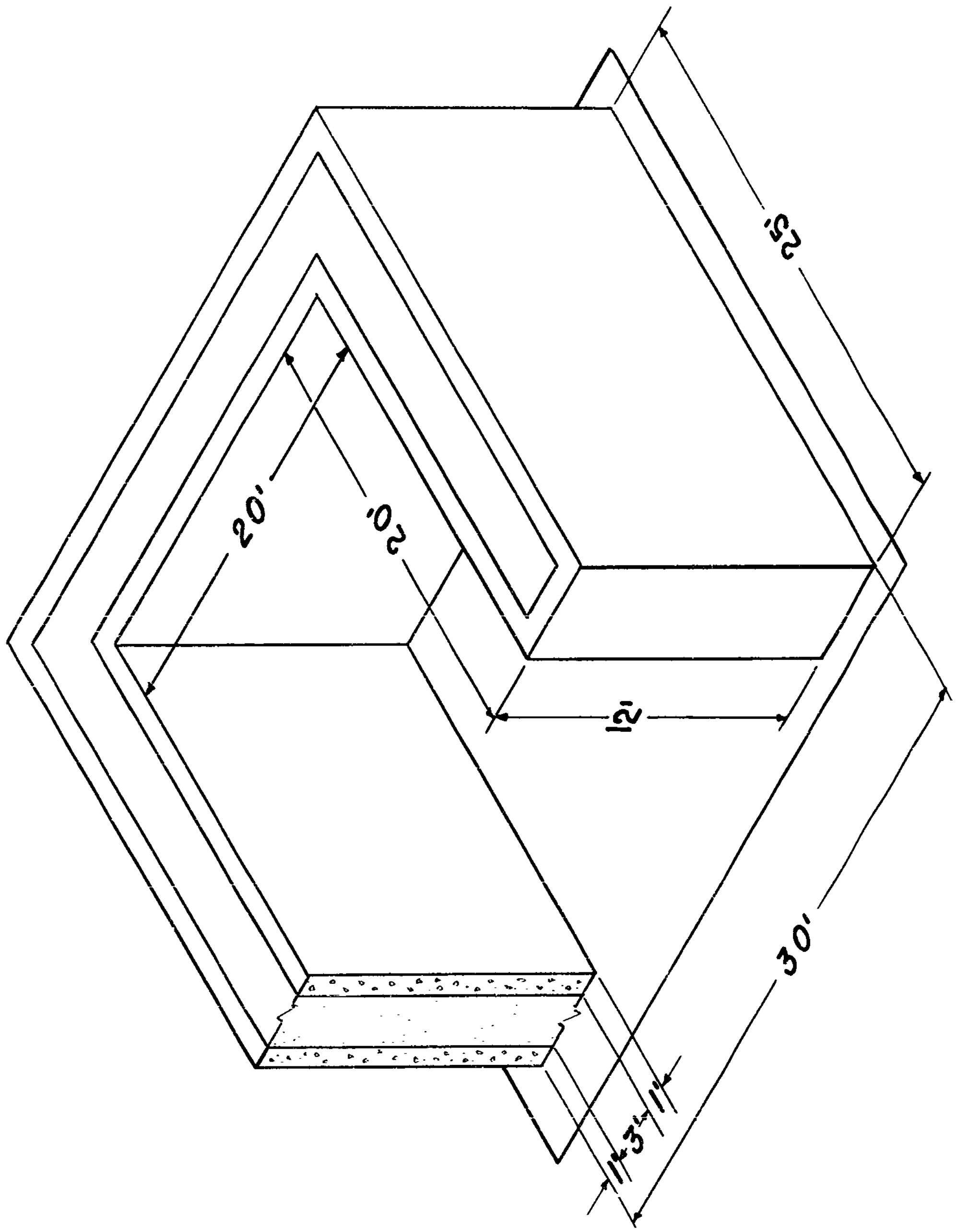
are not adequate and/or practical for protection against close-in explosions involving charges of more than a few hundred pounds. Design of a protective wall for close-in charge locations based on the assumption that the wall is subjected to a plane shock wave, would be, therefore, an over-simplification leading to a serious underestimate of the potential degree of damage and/or likelihood of propagation.

It follows from the preceding discussion, that a means of improving the effectiveness of protective structures is to design overall explosive-protection systems so that protective walls are subjected to plane blast wave loading only, or so that this condition is approached. If we were to limit ourselves to standard reinforced concrete walls, this could be accomplished only by locating the explosive material at relatively great distances from the protective walls (i.e. using the air as an attenuator). As you might guess, and as I will show later in an illustrative example, this approach would be impractical, even prohibitive in many cases, because of construction costs and real estate requirements. A more attractive approach would be to use a type of construction material more effective than concrete as an attenuator, having the additional advantages of (1) substantial mass (unlike air) which would absorb energy during translation resulting from blast loading (like concrete), and (2) being highly frangible, or initially finely subdivided, so that (unlike concrete) it would not transfer any appreciable portion of its acquired kinetic energy during impact with another explosive charge or other materiel. Dry sand or earth meet all these requirements. Based on the use of such materials in protective structures, our analytical studies

have resulted in design relationships which quantitatively show the substantial benefits which they make possible. Referring again to large scale tests recently conducted by the Armed Services Explosives Safety Board, these included tests with (1) storage cubicles constructed of sandwich-type walls, i.e. each side of the cubicle consisting of a layer of sand held between two reinforced concrete walls and (2) storage cubicles consisting of metal multi-plate arches with continuous earth cover and earth fill between them. Results with both structures, and particularly with the multi-plate arches, clearly indicated their advantages over conventional reinforced concrete walls in terms of protection effectiveness and economy.

In order to illustrate the application of our design relationships, including the plane wave aspects previously discussed, let us consider a typical design problem. We will assume a three-sided cubicle constructed with sandwich-type walls consisting of a three feet thick layer of sand held between two one foot thick reinforced concrete walls (Slide 4). The requirement imposed upon this cubicle will be that it must offer adequate protection to personnel and/or materiel on the outside of the rear wall against the damaging effects of detonation of a 400 pound explosive charge inside the cubicle. In other words, the inside dimensions of the cubicle must permit location of the charge relative to the interior walls in a manner which will virtually prevent any substantial damage to the outside face of the rear wall. It should be noted that this requirement is much more severe than a requirement for prevention of explosion propagation only, since the latter would permit a substantial degree of damage to the outside face of

Slide 4



ISOMETRIC OF SANDWICH WALL CUBICLE

the wall. Slide 5 summarizes all the conditions assumed for the illustrative example.

Step 1. Consideration must first be given to total protection against spalling. It may be assumed that if spalling does not occur, punching will not occur. Slide 6 is a chart relating threshold conditions necessary for prevention of spalling in terms of explosive charge weight (W), scaled charge distance (linear distance divided by cube root of charge weight) from wall in question (Z_A), and concrete wall thickness (T). It should be noted that, throughout this paper, the Z subscript A by itself refers to normal scaled distance from the charge to the wall in question. In considering our sandwich rear wall, the portion of interest here is the outside one foot thick concrete wall. As can be seen from the chart, spalling of this wall will not occur beyond a free air $Z_{A(out)}$ value of 2.5. This value approaches the threshold condition for plane wave loading.

Step 2. Preliminary calculations (not detailed in this paper) indicate that for $Z_{A(out)} = 2.5$ the outside one foot thick concrete wall would not withstand the blast load because of excessive shear stresses acting at the base support. It is necessary, therefore to place the charge at a free air scaled distance from the outside concrete wall of $Z_{A(out)} \cong 3.0$. Under these conditions, this wall is subjected to plane wave blast loading.

Step 3. From Slide 7 determine the normal pressure (P_R) and scaled impulse per unit area ($\bar{I}_R$) loading on the front face of the outside concrete

PART I - ILLUSTRATIVE EXAMPLE

CONDITIONS ASSUMED

1.	EXPLOSIVE CHARGE (DONOR) WEIGHT	400 LBS.
2.	WALL HEIGHT	12 FT.
3.	WALL LENGTH AND WIDTH (MAX. SPACE AVAILABLE)	20 FT.
4.	CHARGE HEIGHT ABOVE GROUND	3 FT.
5.	CONCRETE STRENGTH	5,000 PSI
6.	STEEL STRENGTH	50,000 PSI
7.	SAND DENSITY	100 LBS./CU. FT.
8.	SEISMIC VELOCITY OF SHOCK THROUGH SAND	2,000 FT./SEC.
9.	WALL CONSTRUCTION	3' SAND LAYER SANDWICHED BETWEEN TWO 1' REINFORCED CONCRETE WALLS

REQUIRED

1. MINIMUM DISTANCE BETWEEN THE INSIDE CONCRETE WALL AND CENTER OF THE CHARGE.

2. PERCENT AND KIND OF REINFORCEMENT IN THE CONCRETE WALL TO RESIST FLEXURAL FAILURE.

Slide 5

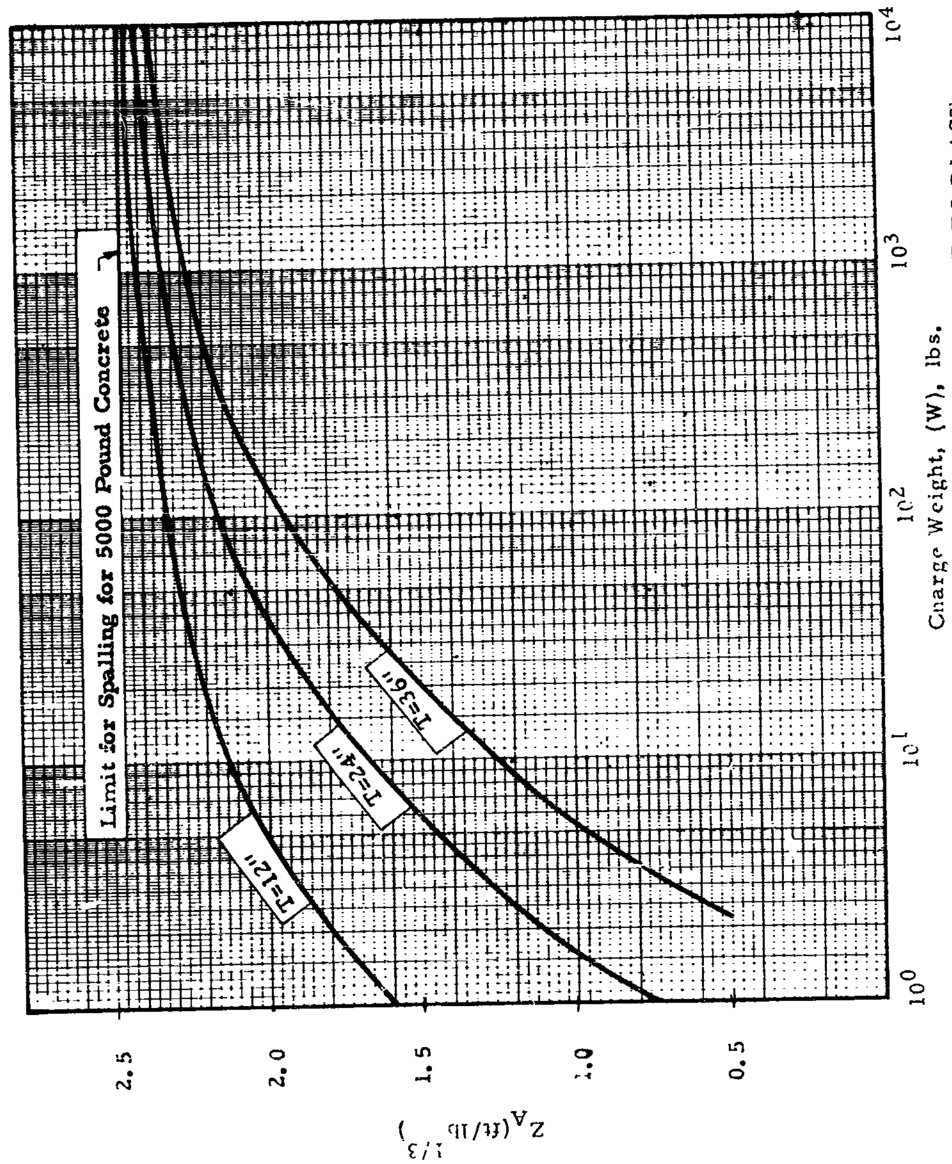
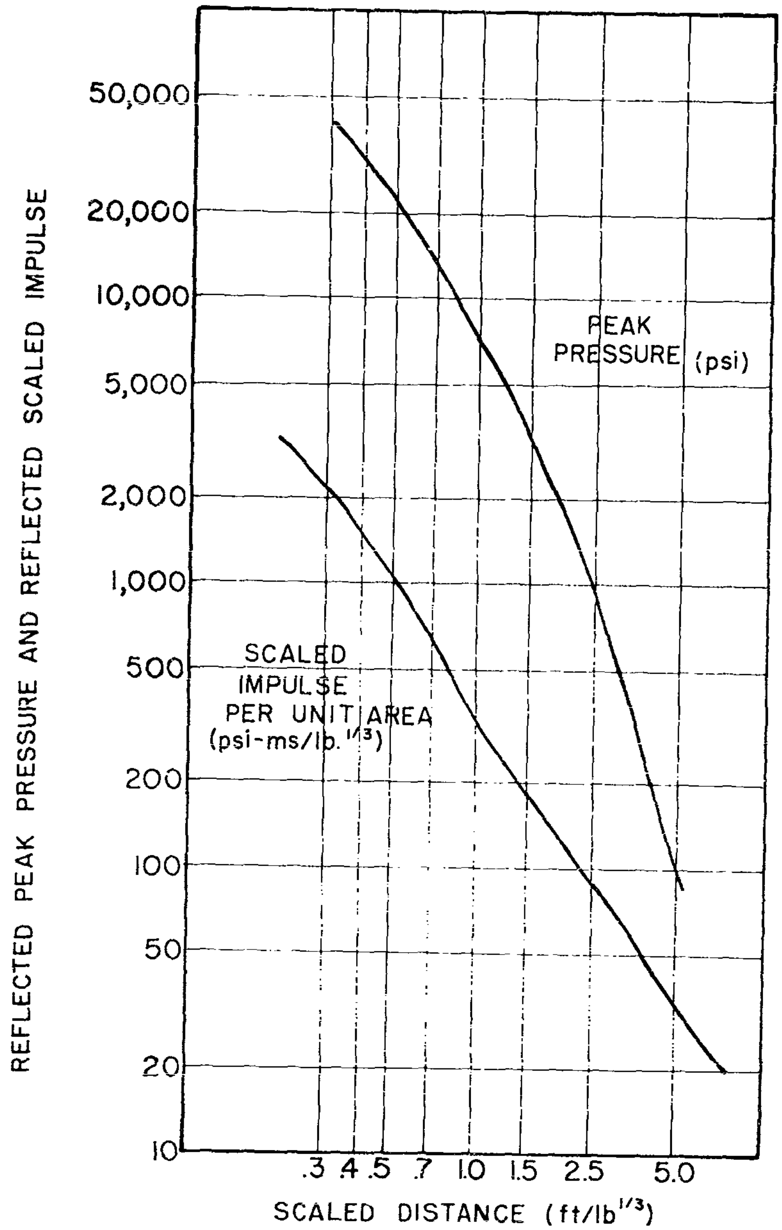


Fig. 3.6 TOTAL PROTECTION FOR SPALLING DUE TO BLAST

Slide 6

PEAK PRESSURE AND SCALED IMPULSE vs SCALED DISTANCE



Slide 7

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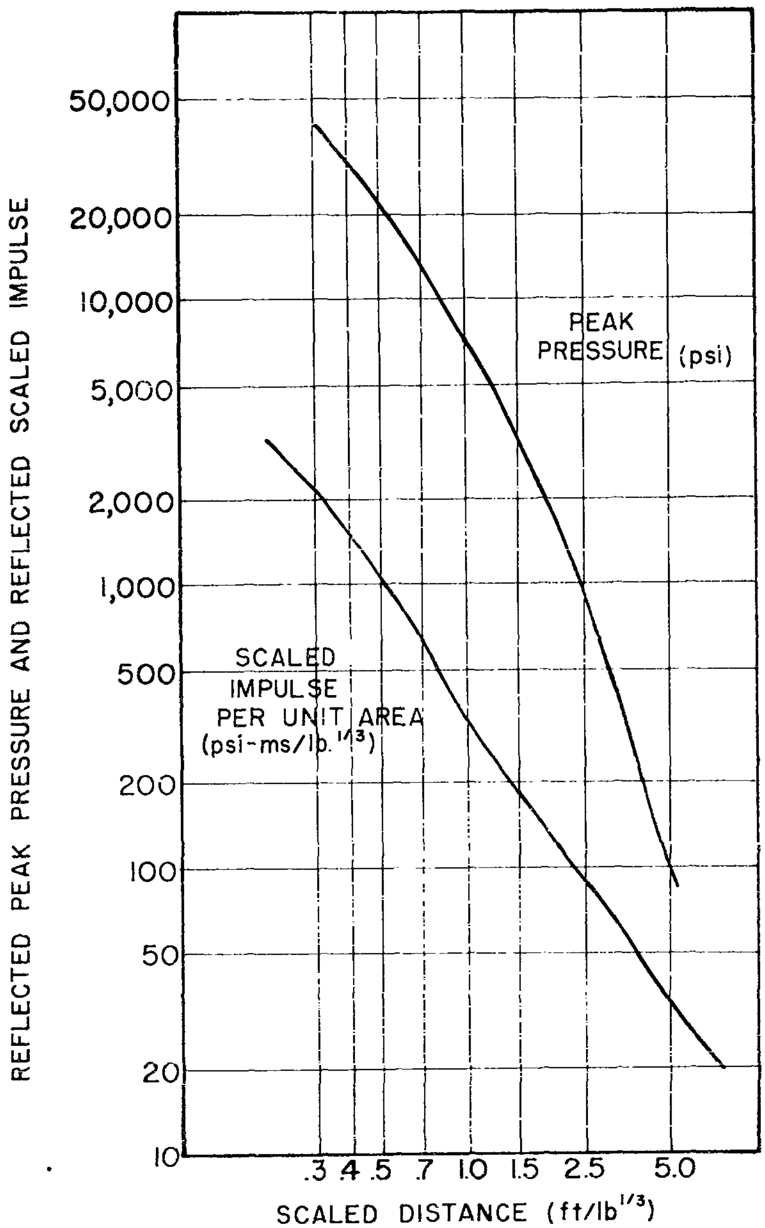
PEAK PRESSURE AND SCALED IMPULSE vs SCALED DISTANCE



Slide 7

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wall for $Z_{A(out)} \cong 3.0$.

$P_R = 500$ psi

$\bar{I}_R = 70$ psi-ms/lb.$^{1/3}$

Step 4. Calculate scaled thicknesses of concrete ($T/W^{1/3}$) and sand ($T_E/W^{1/3}$).

$T/W^{1/3} = 1.0/400^{1/3} = 0.136$

$T_E/W^{1/3} = 3.0/400^{1/3} = 0.41$

Step 5. Slide 8 is a chart for determination of attenuation of peak pressure in sand and concrete as a function of scaled thickness. The solid family of lines refer to concrete, while the broken lines refer to sand. Starting at a point corresponding to the front face of the outside concrete wall locate the point on a broken line corresponding to $T_E/W^{1/3} = 0.41$ and $P_R = 500$. Read vertically upward from this point to the point on a solid line corresponding to $T/W^{1/3} = 0.136$. From this point read horizontally to determine peak pressure (P_F) at the front face of the inside concrete wall.

$P_F = 5500$ psi

It should be noted that this chart accounts for coupling effects between the sand and concrete.

Step 6. Slide 9 is a chart similar to the chart shown on Slide 8, except that it is used for determination of attenuation of scaled impulse per unit area in sand and concrete. By a procedure similar to that used in Step 5, determine scaled impulse per unit area ($\bar{I}_F$) at the front face of the inside concrete wall.

$\bar{I}_F = 500$ psi-ms /lb.$^{1/3}$

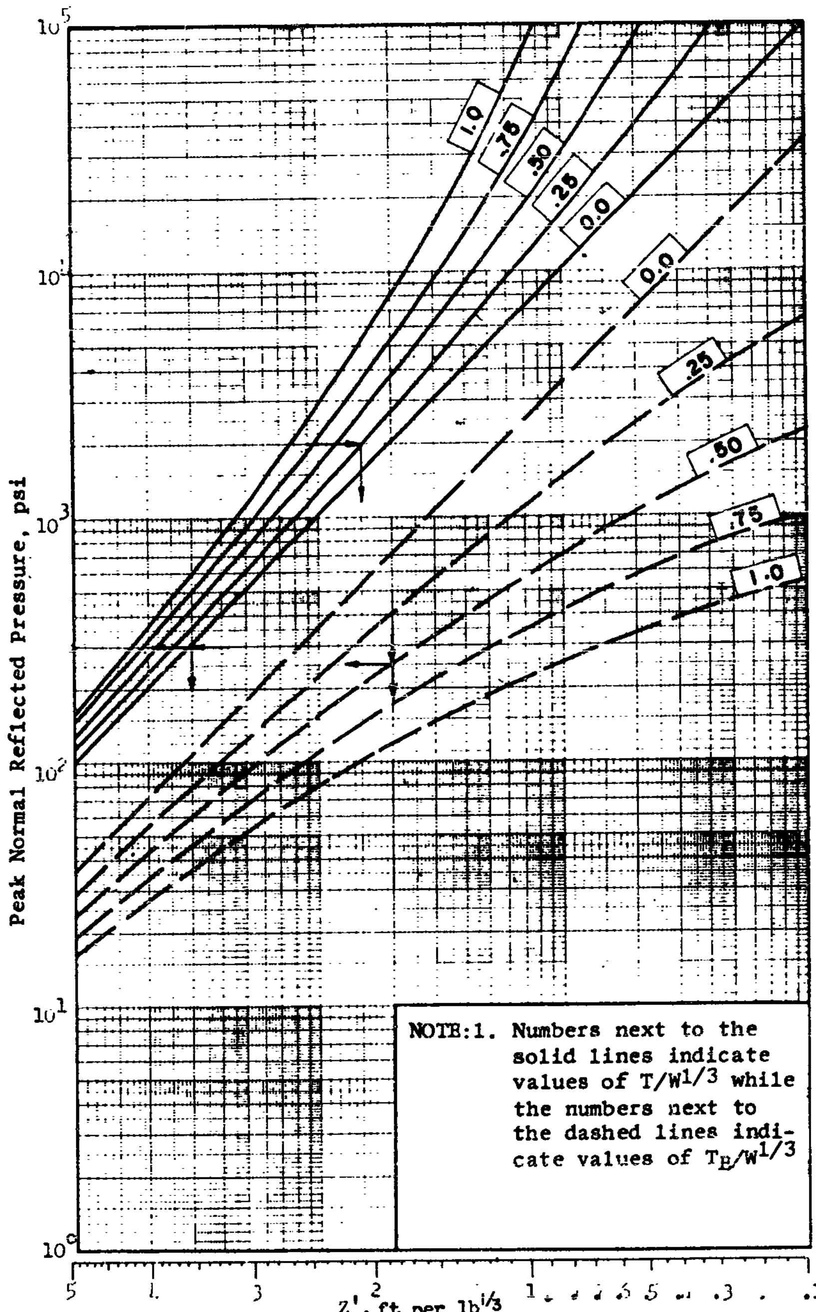

Fig. 3.9 ATTENUATION OF PEAK PRESSURE IN SAND AND CONCRETE

Slide 8

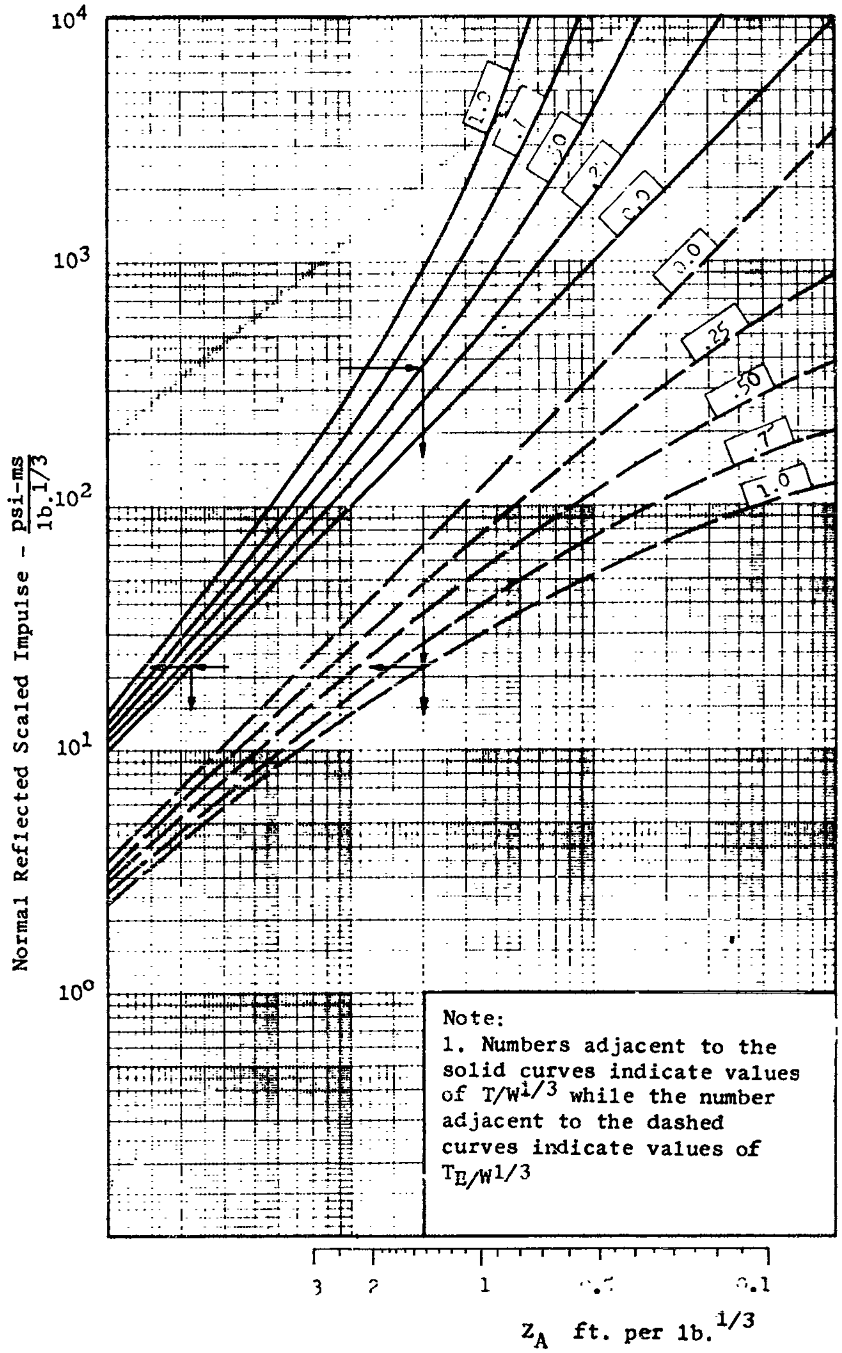

Fig. 3.10 ATTENUATION OF IMPULSE IN SAND AND CONCRETE

Slide 9

Step 7. Determine, from Slide 7, the scaled normal distance from the front face of the inside concrete wall corresponding to $P_F(Z_{A(in)(pressure)})$ and $\bar{I}_F(Z_{A(in)(impulse)})$.

$Z_{A(in)(pressure)} = 1.10$

$Z_{A(in)(impulse)} = 0.80$

Therefore $Z_{A(in)(pressure)} = 1.10$ is controlling scaled distance.

Step 8. Determine reflection effects coming from side walls of cubicle and ground, which enhance blast loading on the rear wall. (Since the method for arriving at the appropriate reflection factor (R_I) is detailed in PART II of this paper, it will not be given at this point).

$R_I = 2.5$

Step 9. Calculate effective weight of charge (W_e)

$W_e = R_I W = 2.5 \times 400 = 1000$ lbs.

Step 10. Using the value of W_e from Step 9 and $Z_{A(in)(pressure)}$ from Step 7, calculate the normal distance (d) from the center of the charge to the front face of the inside wall required for the desired protection.

$d = Z_{A(in)(pressure)} \times (W_e)^{1/3} = 1.10 \times 1000^{1/3} = 11$ feet

Step 11. Recalculate scaled thicknesses of concrete and sand corresponding to W_e.

$T/W_e^{1/3} = 1/10 = 0.1$

$T_E/W_e^{1/3} = 3/10 = 0.3$

Step 12. From Slide 7, determine $\bar{I}_F$ corresponding to $Z_A = 1.10$. Calculate I_F using W_e value from Step 9.

$\bar{I}_F(Z_{A(in)(pressure)}) = 295$ psi-ms/lb.$^{1/3}$

$I_F(Z_{A(in)(pressure)}) = 295\ (1000)^{1/3} = 2950$ psi-ms.

Step 13. Using values of P_F and $\bar{I}_F$ from Steps 5 and 12, respectively, and the scaled thickness values from Step 11, redetermine P_R and $\bar{I}_R$ by a method similar to that used in Steps 5 and 6. Calculate I_R using W_e value from Step 9.

$P_R = 650$ psi

$\bar{I}_R = 55$ psi-ms/lb.$^{1/3}$

$I_R = 55\ (1000)^{1/3} = 550$ psi-ms.

Step 14. Determine. from Slide 7, the scaled normal distance from the front face of the outside concrete wall corresponding to $P_R(Z_{A(out)(pressure)}$ and $\bar{I}_R(Z_{A(out)(impulse)})$.

$Z_{A(out)(pressure)} = 2.8$

$Z_{A(out)(impulse)} = 3.6$

Therefore, $Z_{A(out)(pressure)} = 2.80$ is controlling scaled distance for use in subsequent calculations relating to flexural failure of the outside concrete wall.

We must now check the outside concrete wall for flexural capacity and reinforcement required. This flexural analysis involves determination of the following:

a. bending or moment stresses

b. shear stresses consisting of (1) pure shear (cracking normal to

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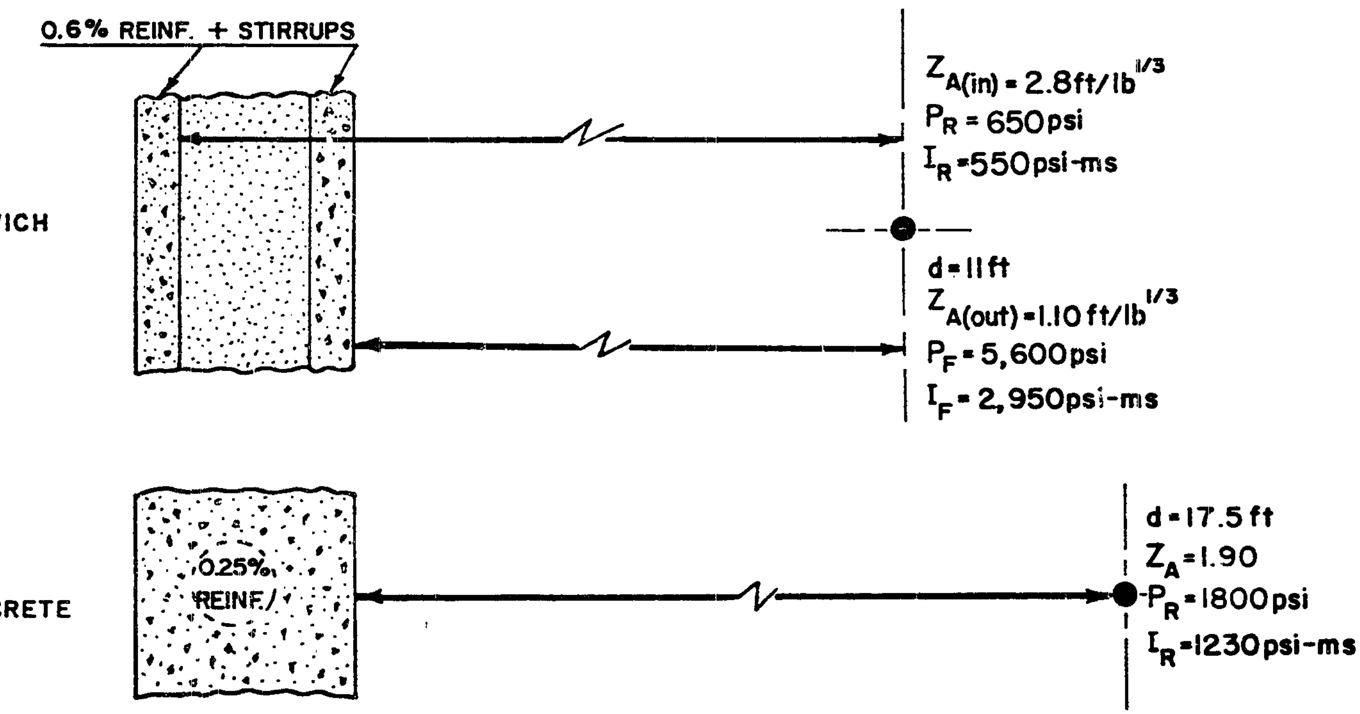

SUMMARY COMPARISON OF SANDWICH WALL & STANDARD CONCRETE WALL FOR TOTAL PROTECTION

Slide 10

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DETERMINATION OF WALL RESPONSES TO BLAST EFFECTS FROM EXPLOSIVE CHARGES DISTRIBUTED IN A CUBICLE TYPE STRUCTURE

by

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This portion of the paper deals with the determination of the magnitude of blast loads in terms of pressure and impulse imposed on a protective wall as a result of detonation of an explosive charge located close to the wall. More specifically, consideration will be given to the often encountered situation where several like charges are to be placed in a storage bay and it is desired to determine the optimum charge distribution for minimization of pressure and impulse loads acting on the walls. It will be conservatively assumed that, regardless of their distribution within the bay, all the charges will detonate in the event of an accident.

This illustrative analysis will consider three typical distributions of four 200 pound explosive charges within a three-sided cubicle. Through step-wise calculations in each case we will determine the net combined maximum pressure and impulse loading on the rear wall in the event of explosion of the donor charges. For comparison purposes, the following conditions have been assumed constant for each case:

a. Three sided storage cubicle 16 feet long, 16 feet wide and 12 feet high.

b. Geometric center of charge configuration located midway between the two side walls of the cubicle.

c. Distance of geometric center of charge configuration to rear wall (4.5 feet).

d. Height of charges above ground (3 feet).

The three different charge arrangements to be considered are as follows:

CASE 1: All four charges are clustered in the center of the cubicle. For all practical purposes the donor charge may be considered as a single symmetrical charge, the center of which is the geometric center of the cluster, and the mass of which is equal to the total mass of the individual charges.

CASE 2: The charges are distributed symmetrically in two groups of two charges each, one group behind the other.

CASE 3: The charges are distributed symmetrically in two groups of two charges each, all the charges lying along a straight line parallel to the rear wall.

For all three charge locations the rear wall is subjected to a combination of free air blast effects and reflected blast effects from adjacent sections of the structure, which enhance the rear wall loading. In order to account for reflection effects, it is necessary to determine, for each donor charge, the reflection factor which is applied as a multiplier to the actual donor charge weight. This reflection factor is defined as the ratio of an equivalent weight of the donor charge detonated in free air to the actual weight of donor charge detonated close to a reflecting surface, the equivalent charge producing essentially the same pressure and impulse loading on the wall in question as the actual donor charge. For utilization of such reflection factors, the type of wall being considered as well as the location of the charge in relation to this wall, to the other cubicle walls, and to the ground must be known. In the specific examples to be considered in this paper, reflections on the rear wall resulting from reflection interactions between the two side walls may be

considered negligible in comparison to direct reflections from the side walls to the rear wall.

Slide 11 is a chart relating reflection factors for walls restrained on two sides (e.g. side walls of the cubicle) or three sides (e.g. rear wall of the cubicle) to (1) scaled distance of the charge (linear distance divided by cube root of charge weight) from the wall being investigated (Z_A), (2) scaled distance between the center line of the wall in question and the adjacent wall (Z_B), (3) ratio of the distance between the charge and the nearest adjacent wall to the length of the wall in question (L/l), and (4) charge height to wall height ratio (h/H). As can be seen from the chart this factor may be of relatively great magnitude for large charges close to the wall. Therefore, failure to take them into account in the calculation of blast loads on the wall may lead to seriously inadequate design of a structure to withstand these loads.

CASE 1 of our illustrative example will now be considered. This is shown schematically in Slide 12

Step 1 Calculate normal scaled distance between the geometric center of the charges and the wall in question $Z_A = \frac{d}{W^{1/3}} = \frac{4.5}{800^{1/3}} = 0.485$ ft/lb.$^{1/3}$.

Step 2 Calculate scaled distance between the center of the cubicle and the side wall (Z_B) $Z_B = \frac{8.0}{800^{1/3}} = 0.86$

Step 3 Using the values for Z_A and Z_B determine the reflection coefficient from Slide 11. For the conditions indicated, namely

Slide 11

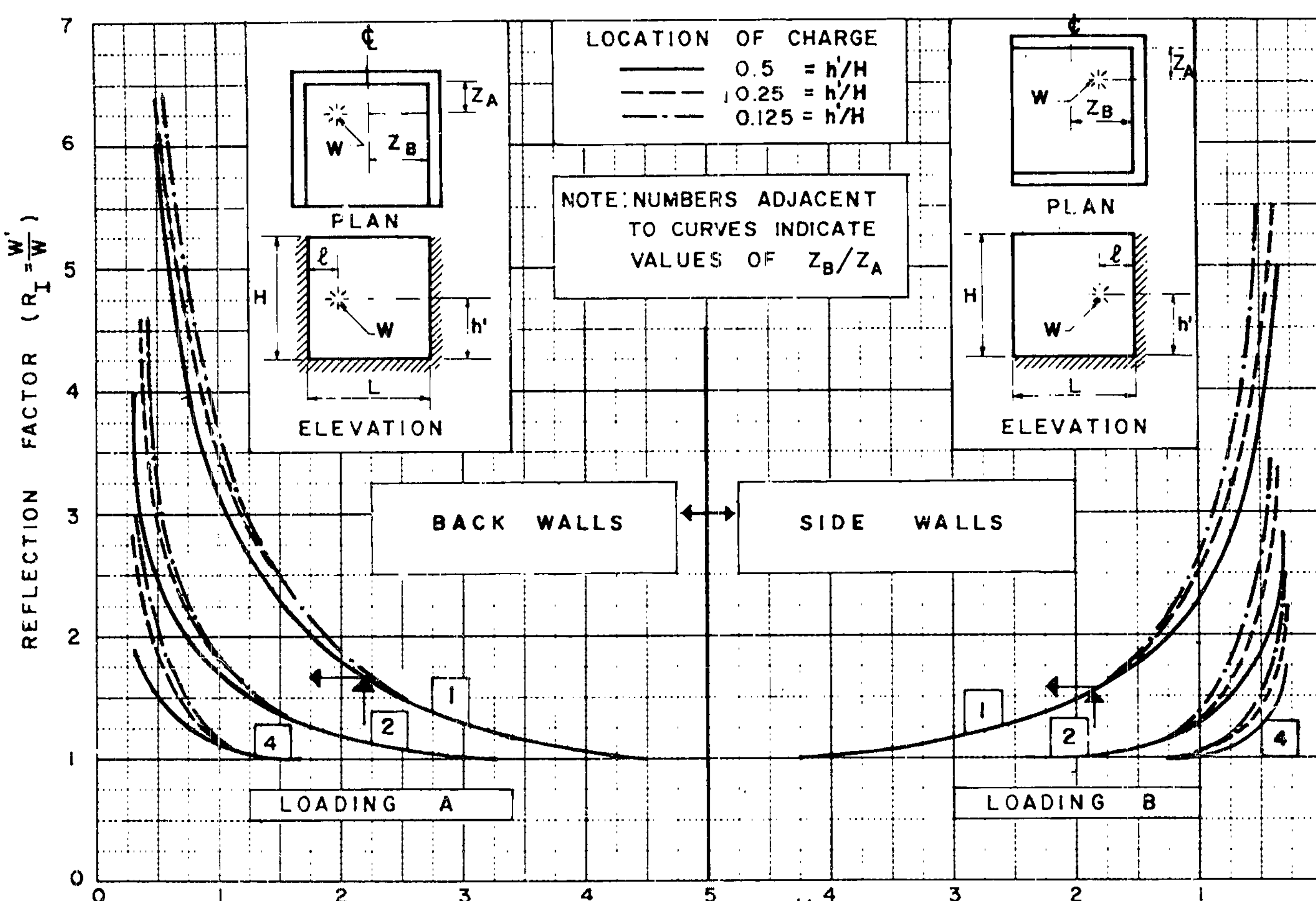
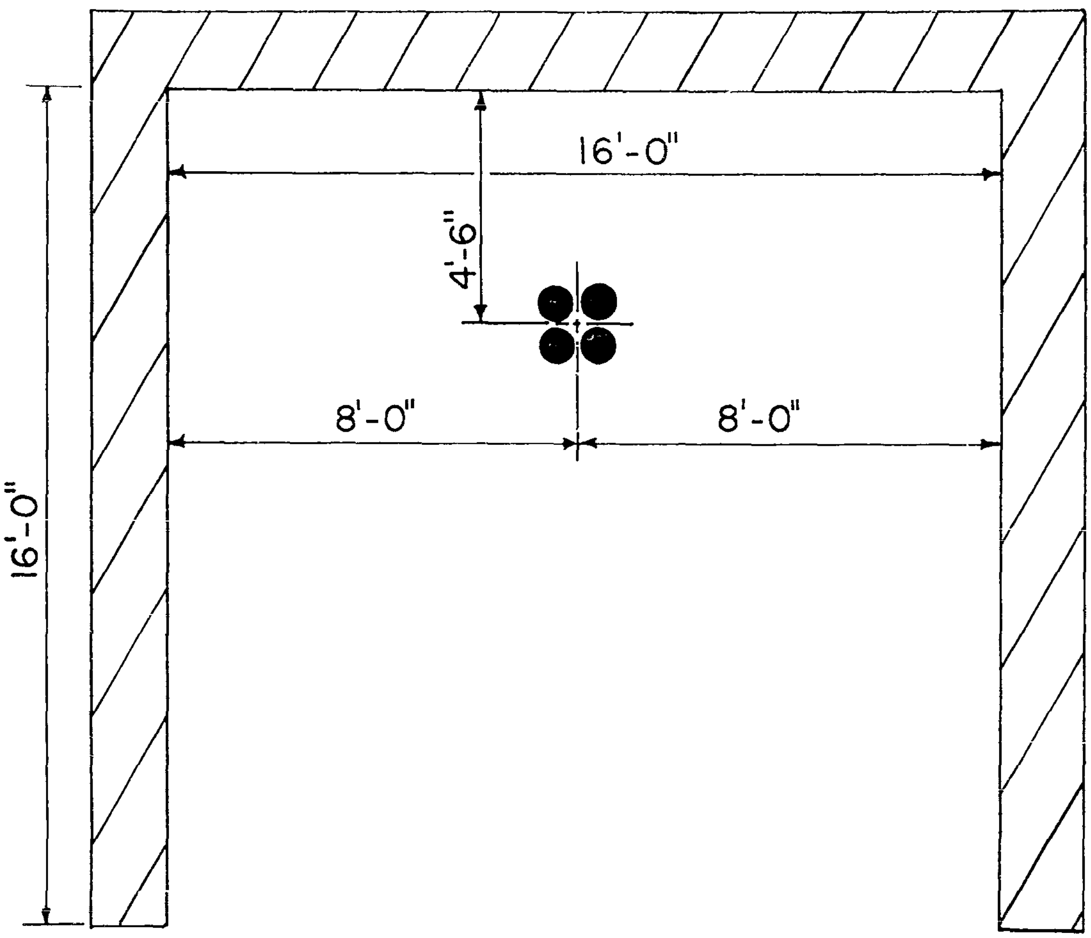


FIG. 2.21 **REFLECTION** FACTORS FOR CUBICLE TYPE STRUCTURES

L = H AND [illegible] = 2



CASE I

Slide 12

$Z_A = 0.485$, $h = H/4$, $Z_B/Z_A = 1.8$, the reflection coefficient would lie between lines 1 and 2 on the reflection chart. Interpolating between these two lines, we obtain a reflection coefficient $(R_I) = 3.5$.

Step 4 Calculate equivalent charge weight (W_c) and corrected scaled distance $(\dot{Z}_A)$ $W_e = W \times R_I = 800 \times 3.5 = 2{,}800$ lbs.

$$\dot{Z}_A = 4.5/2{,}800^{1/3} = 0.32$$

Step 5 From chart relating pressure (P_T) and scaled impulse per unit area $(\bar{I}_T)$ to scaled distance (Slide 7), determine pressure and impulse loads on rear wall for corrected scaled distance.

$$\bar{I}_T = 2{,}000 \text{ psi-ms/lb.}^{1/3}$$

$$P_T = \underline{38{,}000} \text{ psi}$$

Calculate impulse per unit area

$$I_T = \bar{I}_T \times W^{1/3} = 2{,}000 \times 2{,}800^{1/3} = \underline{28{,}000} \text{ psi-ms}$$

Let us now consider CASE 2 as shown schematically in Slide 13. This example will illustrate the method for determining mass and location of a single equivalent charge which would produce essentially the same pressure and impulse loads on the rear wall as the four actual charges in the indicated configuration. It will also serve to compare the blast load produced by this configuration with the blast load from a single charge cluster as presented in CASE 1.

Step 1. Calculate scaled distance between each charge and the rear wall.

$$Z_A(W_a) = Z_A(W_b) = 3/200^{1/3} = 0.515$$

$$Z_A(W_c) = Z_A(W_d) = 6/200^{1/3} = 1.03$$

Step 2. Calculate scaled distance Z_B between the center of the cubicle and the side walls $Z_B = 8.0/200^{1/3} = 1.37$

Step 3. Using the values of Z_A and Z_B from Steps 1 and 2 calculate the value of Z_B/Z_A for each charge

$$Z_B/Z_A(W_a) = Z_B/Z_A(W_b) = 1.37/0.515 = 2.66$$

$$Z_B/Z_A(W_c) = Z_B/Z_A(W_d) = 1.37/1.03 = 1.33$$

Step 4. Using the values from Steps 1 through 3 determine the reflection factors for each charge from Slide 11.

$$\text{for } W_a \text{ and } W_b, R_I = 2.25 \begin{pmatrix} L/l = 2.6 \\ Z_B/Z_A = 2.66 \end{pmatrix}$$

$$\text{for } W_c \text{ and } W_d, R_I = 2.75 \begin{pmatrix} L/l = 2.6 \\ Z_B/Z_A = 1.33 \end{pmatrix}$$

Step 5. Calculate equivalent weight of the individual charges using the respective values of reflection coefficient R_I from Step 4.

$$\dot{W}_a = \dot{W}_b = 2.25 \times 200 = 450 \text{ lbs.}$$

$$\dot{W}_c = \dot{W}_d = 2.75 \times 200 = 550 \text{ lbs.}$$

Step 6. Using the values obtained in Step 5 for each charge calculate the adjusted normal scaled distance between each charge and the rear wall.

$$\dot{Z}_A(\dot{W}_a) = \dot{Z}_A(\dot{W}_b) = 3.0/450^{1/3} = 0.40$$

$$\dot{Z}_A(\dot{W}_c) = \dot{Z}_A(\dot{W}_d) = 6.0/550^{1/3} = 0.74$$

Step 7. Using the adjusted values for scaled distance from Step 6 and equivalent weights from Step 5 determine, from Slide 7 the impulse on the

wall normal to each equivalent charge

$\bar{I}(\dot{W}_a) = \bar{I}(\dot{W}_b) = 1,350$

$\bar{I}(\dot{W}_c) = \bar{I}(\dot{W}_d) = 550$

$I(\dot{W}_a) = I(\dot{W}_b) = \bar{I}(W_a) \times \dot{W}_a = \bar{I}(W_b) \times \dot{W}_b = 1,350 \times 450^{1/3} = 10,300$ psi-ms

$I(W_c) = I(W_d) = 550 \times 550^{1/3} = 4,500$ psi-ms

Step 8. Sum up charges in each group to determine equivalent group charge

$\dot{W}_a + \dot{W}_c = \dot{W}_b + \dot{W}_d = 450 + 550 = 1,000$ lbs.

Step 9. Sum impulse for each group to determine equivalent group charge normal impulse at points A and B (refer Slide 13 for this step and subsequent steps)

$I_A(\dot{W}_{ac}) = I_B(\dot{W}_{bd}) = 10,300 + 4,500 = 14,800$ psi-ms

Step 10. Using the values of $\dot{W}$ and I from Steps 8 and 9 calculate the scaled values of the impulse load above

$\bar{I}(\dot{W}_{ac}) = \bar{I}(\dot{W}_{bd}) = 14,800/1,000^{1/3} = 1,480$

Step 11. Using the value $\bar{I}$ from Step 10 determine the value of $\dot{Z}_A$ from Slide 7 for each group. Calculate the actual distance $(\dot{d})$ between the wall and the equivalent charges

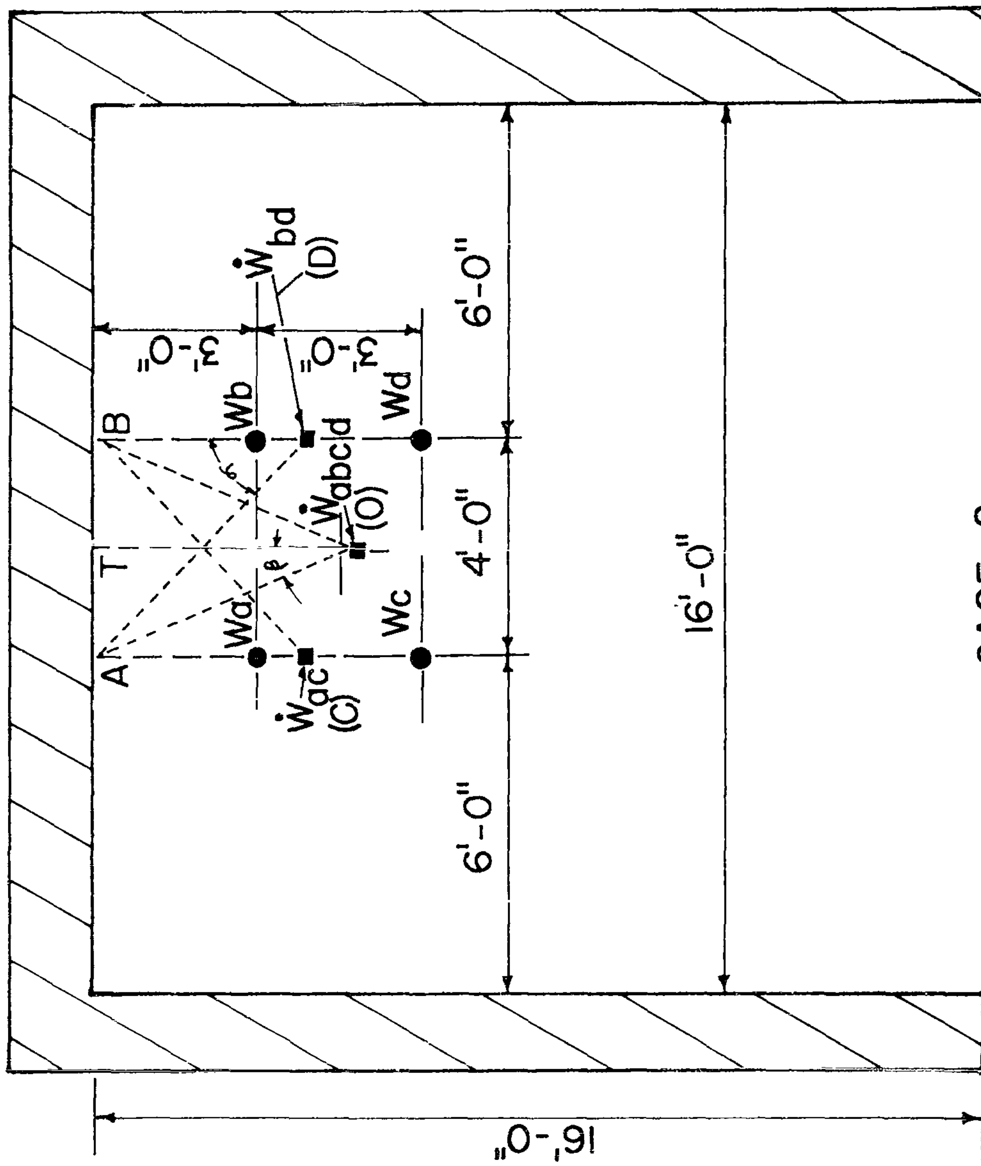
$\dot{Z}_A(\dot{W}_{ac}) = \dot{Z}_A(\dot{W}_{bd}) = .40$

$\dot{d}_{AC} = \dot{d}_{BD} = .40 \times 1,000^{1/3} = 4.0$ ft.

Step 12. Using the values of $\dot{W}$ from Step 9 calculate the total equivalent charge of the entire system

$\dot{W}_{abcd} = 1,000 + 1,000 = 2,000$ lbs.

Slide 13



CASE 2

<u>Step 13</u>. Calculate the slant distances between the wall and the equivalent group charges. Calculate the scaled values of these distances using the value of $\dot{W}$ of step 8. Calculate the angles (α) formed by the lines defining these scaled distances and the normal distance between the equivalent group charges. (See <u>Slide 13</u>).

$$\dot{d}_{AD} = \dot{d}_{BC} = (4^2 + 4^2)^{\frac{1}{2}} = 5.65 \text{ ft.}$$

$$\dot{Z}_{AD} = \dot{Z}_{BC} = 5.65/1000^{1/3} = 0.565$$

$$\tan\alpha_C = \tan\alpha_D = 4/4 = 1.0$$

$$\alpha_C = \alpha_D = 45^\circ$$

<u>Step 14</u>. <u>Slide 14</u> is a chart relating impulse per unit area as a function of scaled distance and angle of incidence α. Using the scaled distance and angle of incidence computed in Step 13 and this chart, determine, the scaled impulse load, for each equivalent group charge, acting at a point on the wall normal to the charge, which is due to the other equivalent group charge. Calculate the actual impulse loads using the values of $\dot{W}$ from step 8

$$\bar{I}_A(\dot{W}_{bd}) = \bar{I}_B(\dot{W}_{ac}) = 335$$

$$I_A(\dot{W}_{bd}) = I_B(\dot{W}_{ac}) = 335 \times 1000^{1/3} = 3{,}350 \text{ psi-ms}$$

<u>Step 15</u>. Calculate the total impulse acting on points A and B using impulse values from Steps 9 and 14. Calculate total scaled impulse.

$$I_A(\dot{W}_{bd}) + I_A(\dot{W}_{ac}) = 14{,}800 + 3{,}350 = 18{,}150 = I_B(\dot{W}_{bd}) + I_B(\dot{W}_{ac})$$

$$\overline{I_A(\dot{W}_{bd}) + I_A(\dot{W}_{ac})} = 18{,}150/2000^{1/3} = 1{,}440 = \overline{I_B(\dot{W}_{bd}) + I_B(\dot{W}_{ac})}$$

Slide 14

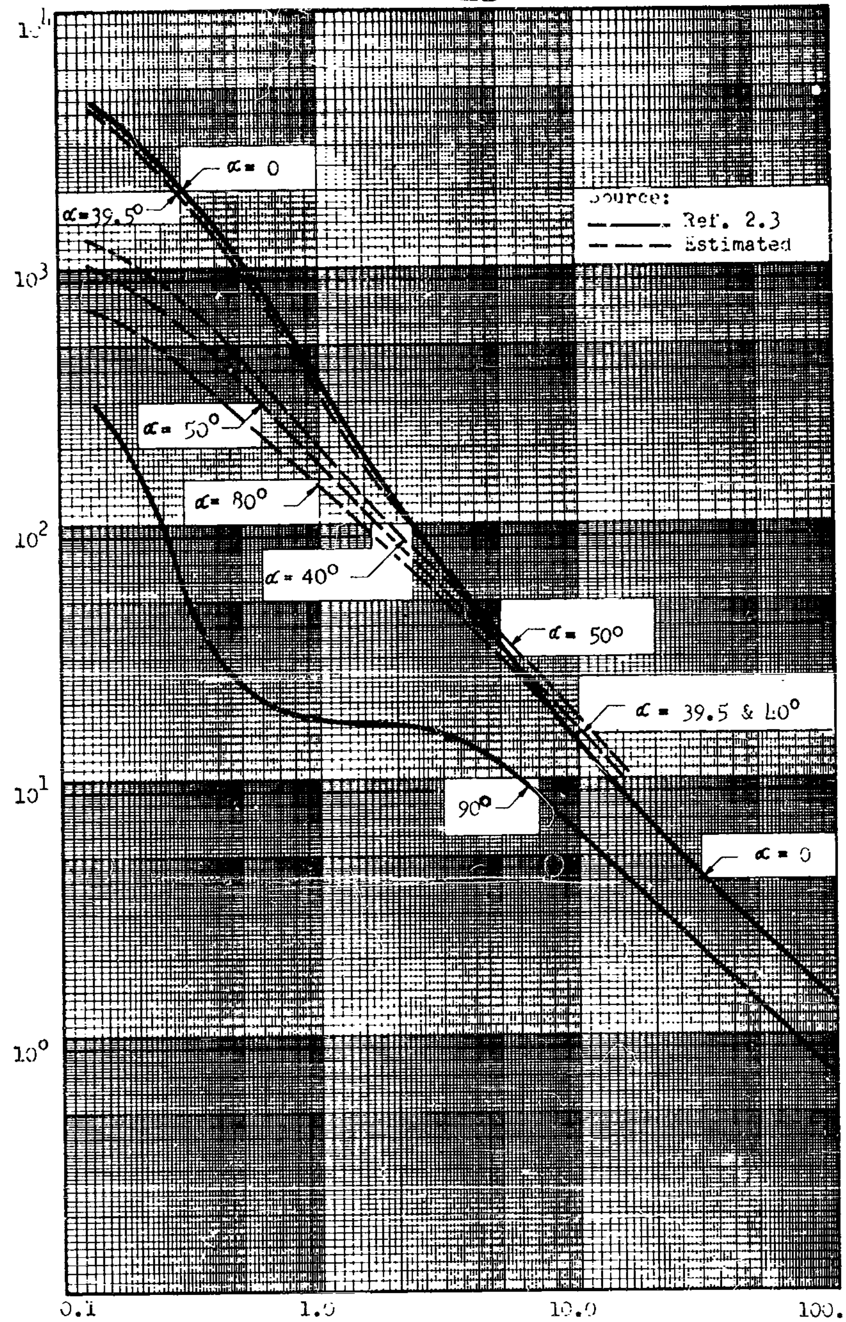


Fig. 2.10 RECOMMENDED REFLECTED POSITIVE IMPULSE (Free Air)

Slide 14

Step 16. Based upon the scaled impulse load calculated in Step 15 determine from Slide 14 the scaled slant distance between the total equivalent charge of the whole system and points A and B. Calculate the actual distance using $\dot{W}$ value from Step 12.

$$\dot{Z}_{OA} = \dot{Z}_{OB} = 0.4$$

$$\dot{d}_{OA} = \dot{d}_{OB} = .4 \times 2000^{1/3} = 5.0 \text{ ft.}$$

Step 17. Calculate angle β

$$\sin\beta = \dot{d}_{AT}/\dot{d}_{AO} = 2.0/5.0 = 0.4$$

$$\beta = 24^{\circ}$$

(Available data indicates a sudden change in impulse patterns occurs at an angle of 40°. If this value is less than 40°, as is true in this case, it is valid to determine a single equivalent point on the wall at which the total equivalent charge for the entire system exerts maximum impulse. If, on the other hand, this angle is 40° or greater this assumption is not valid, as will be covered further under CASE 3.)

Step 18. Using the slant distance from Step 16 calculate the normal distance and scaled normal distance between the wall and the total equivalent charge of the entire system. Determine the maximum local scaled impulse and pressure of the entire system acting on the rear wall from Slide 7 Calculate maximum local impulse using $\dot{W}$ value from Step 12.

$$\dot{d}_{OT} = (\dot{d}_{OA}^{2} - \dot{d}_{AT}^{2})^{\frac{1}{2}} = (5.0^{2} - 2.0^{2})^{\frac{1}{2}} = 4.58 \text{ ft.}$$

$$\dot{Z}_{A}(\dot{W}_{abcd}) = 4.58/2000^{1/3} = 0.360$$

$$\bar{I}_{T} = 1700$$

$$\underline{P_{T} = 34{,}000 \text{ psi}}$$

$$I_{T} = 1700 \times 2000^{1/3} = \underline{21{,}400 \text{ psi-ms}}$$

We will now consider CASE 3 as shown schematically on Slide 15. As will be shown in this example, the distribution of individual charges in a straight line along the rear wall does not result in a single concentration of loading on the wall, but rather two distinct points of concentration of lesser magnitude.

Step 1. By a series of calculations similar to those used in CASE 2 up to Step 10 we arrive at the following:

$\dot{W}_{ab} = \dot{W}_{cd} = 1150$ lbs.

$\dot{d}_{EG} = \dot{d}_{FH} = 4.25$ ft.

$\dot{Z}_A(\dot{W}_{ab}) = \dot{Z}_A(\dot{W}_{cd}) = 0.405$ ft/lb.$^{1/3}$

$I_E(\dot{W}_{ab}) = I_F(\dot{W}_{cd}) = 15{,}700$ psi-ms

(Refer to Slide 15 for this step and subsequent steps).

Step 2. Calculate distances $\dot{d}_{GF}$ and $\dot{d}_{HE}$ and corresponding scaled distances using $\dot{W}$ value from Step 1.

$\dot{d}_{GF} = \dot{d}_{HE} = (4.25^2 + 8^2)^{\frac{1}{2}} = 9.0$ ft.

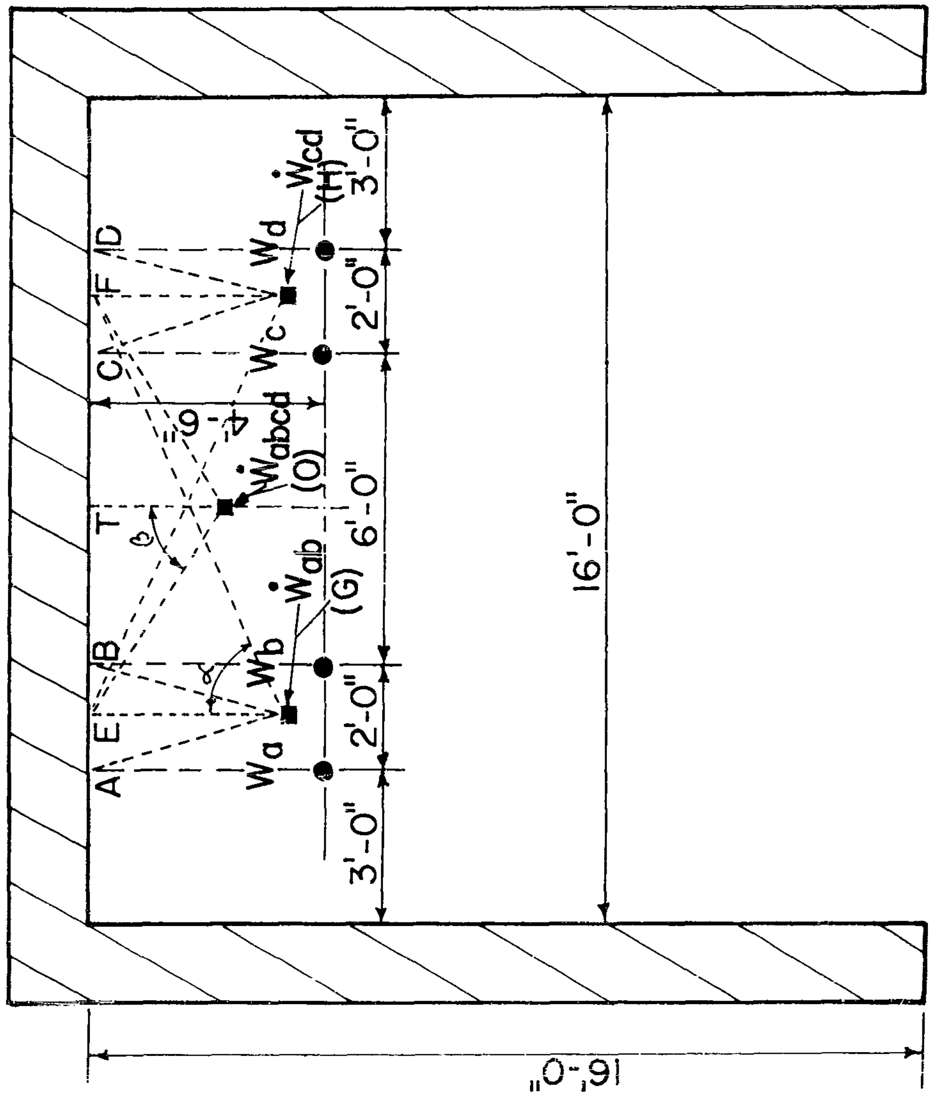
$\dot{Z}_{GF} = \dot{Z}_{HE} = 9.0/1150^{1/3} = 0.86$

Step 3. Calculate angle α

$\tan \alpha = d_{EF}/\dot{d}_{EG} = 8.00/4.25 = 1.87$

$\alpha = 62^\circ$

Step 4. Using the scaled distance and angle of incidence from Steps 2 and 3, determine from Slide 14 the scaled impulse load, for each equivalent group charge, acting at a point on the rear wall normal to the charge, which is due to the other equivalent group charge. Calculate the



CASE 3

Slide 15

actual impulse loads using value of $\dot{W}$ from Step 1.

$$\bar{I}_E(\dot{W}_{cd}) = \bar{I}_F(\dot{W}_{ab}) = 180$$

$$I_E(\dot{W}_{cd}) = I_F(\dot{W}_{ab}) = 180 \times 1150^{1/3} = 1900 \text{ psi-ms}$$

Step 5. Calculate total equivalent charge for entire system using $\dot{W}$ values from Step 1.

$$\dot{W}_{abcd} = \dot{W}_{ab} + \dot{W}_{cd} = 1{,}150 + 1{,}150 = 2{,}300 \text{ lbs.}$$

Step 6. Calculate the total impulse acting on points E and F using impulse values from Steps 1 and 4. Calculate scaled impulses corresponding to these values, using $\dot{W}$ value from Step 5.

$$I_E(\dot{W}_{ab}) + I_E(\dot{W}_{cd}) = I_F(\dot{W}_{cd}) + I_F(\dot{W}_{ab}) = 15{,}700 + 1{,}900 = 17{,}600 \text{ psi-ms}$$

$$\overline{I_E(\dot{W}_{ab}) + I_E(\dot{W}_{cd})} = \overline{I_F(\dot{W}_{cd}) + I_F(\dot{W}_{ab})} = 17{,}600/2{,}300^{1/3} = 1{,}330$$

Step 7. Using the total scaled impulse value from Step 6, determine from Slide 14, the scaled distance for the total equivalent charge weight acting at points E and F. Calculate the actual distance using the $\dot{W}$ value from Step 5.

$$\dot{Z}_{OE} = \dot{Z}_{OF} = 0.43$$

$$\dot{d}_{OE} = \dot{d}_{OF} = 0.43 \times 2300^{1/3} = 5.6 \text{ ft.}$$

Step 8. Calculate angle β

$$\sin\beta = \dot{d}_{ET}/\dot{d}_{OE} = 4.0/5.6 = 0.72$$

$$\beta = 46^\circ$$

Since this angle is greater than 40°, we cannot assume that the total equivalent charge for the entire system exerts a single maximum impulse at one point on the wall (see CASE 2, Step 16). The overall resultant effect must therefore be considered to be two points of equal maximum impulse per unit area (E and F),

due to the total equivalent charge. This value was previously calculated in Step 6 as 17,600 psi-ms. It is important to note that this maximum value is substantially less than it would be in a similar situation where a single maximum value (i.e. where β is less than 40°) would apply.

Thus I_T = 17,600 psi-ms

P_T = 26,000 psi (from Slide 7)

A summary of results for CASES 1, 2 and 3 is presented in Slide 16. It is clear that for a given total charge weight composed of individual charges, distribution of charges within a given cubicle results in significant reduction of blast loading on the walls as compared to clustering the charges. In our particular example in which only the rear wall was considered, distribution of charges in a straight line parallel to this wall appears to be particularly advantageous. It is important to note, however, that to complete the design analysis each charge configuration would have to be considered relative to each wall of the cubicle to result in an optimum configuration for the protection desired.

The next step in the design procedure would be calculation of wall responses in terms of spalling, punching, flexural failure, total destruction, and primary missile penetration. These calculation procedures were illustrated in papers presented at the previous Explosives Safety Seminars and are included in the minutes thereof.

PART II - SUMMARY OF RESULTS

	MAXIMUM IMPULSE PER UNIT AREA, psi-ms	MAXIMUM PRESSURE, psi
CASE 1	28,000	38,000
CASE 2	21,400	34,000
CASE 3	17,600	26,000

Slide 16

We feel, very strongly, that the safety design criteria program represents a major, and long-needed, step forward in ordnance technology. Progress to date shows every promise of far-reaching and continuing benefits to all the services, defense agencies, and private industry with respect to (1) permitting most effective use of existing storage and manufacturing facilities and (2) minimization of protective construction costs for new facilities and missile launching sites.

References

1. "Industrial Engineering Study to Establish Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations" (unpublished report); Ammann & Whitney, Consulting Engineers; under Contract DA-28-017-501-ORD-3889 for Process Engineering Laboratory, Picatinny Arsenal; 1961.

2. "Loading Characteristics of Air Blasts from Detonating Charges;" S. A. Granstrom, Transactions of Royal Institute of Technology; Stockholm, Sweden; 1956.

Mr. Weintraub: In your particular study, you have considered simultaneity as far as the charges going off. What if these are non-simultaneous? What if there is a lag, in other words, is what I'm getting at?

Mr. Rindner: The effect would be much less because you have a delay. We considered the worst case possible in that all of this detonates simultaneously. This is the reason you have to consider the entire amount at one time.

Mr. Weintraub: In other words, you're saying that if you have a reinforced wave, this does not do more damage than if you let the whole thing go off.

Mr. G. R. King: This should have been directed to your predecessor, but I was wondering if these two types of construction, the solid wall vs the sandwich wall, assuming that we had to have a 5' wall for this particular facility, do you have some construction costs that compare the solid wall vs the sandwich wall?

Mr. Rindner: No, I don't have. As far as the cost is concerned, we didn't calculate the cost yet.

Mr. Thomas: In considering the several geometries, have you considered whether or not the reflected and incident shock waves have had time to combine into one shock wave or might they arrive non-simultaneously and increase the impulse and the time effects of the loading of the wall?

Mr. Rindner: Well, we thought that the highest impulse will be in the case when all of them detonate simultaneously to produce the maximum impulse. If you have a delay you are not going to get the highest possible impulse.

Mr. Thomas: I wasn't speaking of the time between charges but whether or not the reflected and incident wave from one charge have recombined, you gave some reflection factors. Are these calculated beyond the point at which the two waves have combined?

Mr. Rindner: Yes, they are calculated from actually all the effects of interaction. You actually have a little reduction because of this.

Mr. Thomas: Your impulse loading might be worse depending on the periodic time of the structure if the two waves arrive at slightly different times.

Mr. Rindner: I don't think so. I still think that you have the highest under the conditions between indicated in case 1.

Mr. Saffian: I think possibly Mr. Rindner may be misunderstanding the question. Let me see if I can clear it up. First of all these reflection factors if you'll notice, the ratios of z_b to z_a and the values of z_a consider the time of arrival of the reflections in relation to the time of arrival of the shock front of the initial blast loading on the wall. Depending on the ratio of z_b to z_a, these things have been taken into account in terms of the fact that you may get a greater enhancement for particular relative distances so to speak as z_b to z_a. In other words, I think what the question refers to is the fact that in the event that you are very close to the wall with the charge and by the time the mock front due to the reflection hits the wall, the wall has already responded to the initial front. This is one case whereas in the other case, you have ample time for the reflection to reinforce the original shock wave where you may get a greater enhancement and thereby greater reflection factor. Is that the question? Okay, this is very definitely taken into account in these reflection charts. There was another question initially, from Mr. Weintraub, I think your question was does the simultaneity of detonation necessarily represent the worst case. Well - along the same lines, it does not represent the worst case. I don't think Mr. Rindner understood that properly. However, I think you have to have a very special set of conditions for a case like that to be worse than simultaneous detonation and again answering your question specifically, we have not considered the case where you have non-simultaneity. Based on the assumption that altho there is a slight chance of getting an effect worse than the simultaneous effect, the chance of this is slight and in most cases where we do not have simultaneity, I think the effect would be less and I think this is what Mr. Rindner was trying to say.

THERMAL STABILITY OF SOLID PROPELLANTS[1]

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INTRODUCTION

Very early during the development of a new propellant when only small amounts of propellant are available, it would be desirable if the answers to two questions could be obtained. How long could a large motor of this propellant be stored at a given high temperature before it would explode? What is the critical temperature for a large motor, the maximum storage temperature which will never cause an explosion? The process of answering these questions which will be described in this paper consists of performing small scale thermal stability experiments, reducing this data to obtain the constants which determine the rate of heat evolution resulting from decomposition of the propellant as a function of temperature, and then calculating, by digital computer techniques, the answers to the questions about the large motors. The accuracy of the answers depends very much on the adequacy of the mathematical model used in reducing the small scale data and on the adequacy of the mathematical model used for the calculations about the behaviour of the large motor. These two models may be identical or different. Our concern will be the single model used in this work. It should be pointed out that this model is a simple one, but is easily made more complex if necessary.

[1]This work was carried out under Army Ordnance Contract DA-01-021-ORD-11878.

MODEL

The model contains the following elements:

1. The propellant charge has the geometry of a solid cylinder of infinite length.

2. Heat generation results from a first order decomposition or from a first order and a concomitant autocatalytic decomposition.

3. The autocatalyst can not escape from the propellant charge.

4. Heat is transferred through the propellant by conduction.

5. There is perfect thermal contact between the surface of the charge and the constant temperature surroundings.

6. All of the physical and kinetic constants are independent of temperature.

The equations implied by this model are

$$\frac{\partial \theta(\rho, \tau)}{\partial \tau} = \frac{1}{\rho} \frac{\partial \theta(\rho, \tau)}{\partial \rho} + \frac{\partial^2 \theta(\rho, \tau)}{\partial \rho^2} - \nu \frac{\partial \phi(\rho, \tau)}{\partial \tau}$$

$$0 < \rho < 1, \quad \tau > 0$$

and

$$\frac{\partial \phi(\rho, \tau)}{\partial \tau} = -\mu\phi(\rho, \tau) \exp[-1/\theta(\rho, \tau)] - \kappa\phi(\rho, \tau)[1-\phi(\rho, \tau)] \exp[-\lambda/\theta(\rho, \tau)]$$

$$0 < \rho < 1, \quad \tau > 0$$

where

$$\theta = \frac{RT}{E_1}$$

$$\phi = \frac{C}{C_o}$$

$$\tau = \frac{Dt}{b^2}$$

$$\rho = \frac{r}{b}$$

are the dimensionless variables and

$$\nu = \frac{QRC_0}{cE_1}$$

$$\mu = \frac{Z_1 b^2}{D}$$

$$\kappa = \frac{Z_2 b^2 C_0}{D}$$

$$\lambda = E_2/E_1$$

are the dimensionless constants. The calculations involved in fitting the experimental data, and in performing the extrapolations, were carried out in terms of the dimensionless variables and constants.

The definition of the terms combined in the dimensionless variables and constants are:

R - universal gas constant

T - absolute temperature

E_1 - activation energy for the first order decomposition

C - reactant concentration

C_0 - initial reactant concentration

D - thermal diffusivity

t - time

b - outside radius of cylinder

r - perpendicular distance from cylinder centerline to any point within the cylinder

Q - heat of decomposition of the reactant

c - heat capacity of the propellant

Z_1 - pre-exponential factor for the first order decomposition

Z_2 - pre-exponential factor for the autocatalytic decomposition

E_2 - activation energy for the autocatalytic decomposition

EXPERIMENTAL

Experimental explosion time-temperature data were obtained at two charge diameters, 0.210 in. and 1.07 in. The experiments involved raising the surface of the charge quickly from room temperature to a constant high temperature. The high temperature and the time required for explosion to be initiated were both observed. This experiment was performed at a number of surface temperatures with the 0.210-in. and 1.07-in. diameter charges. The propellant studied is a new propellant based on 2,3-bis-difluoramino-propyl acrylate. The formulation for this propellant, designated SA-1, will be mentioned in a later paper by Mr. John Parrott.[1]

The 0.210-in. charges of propellant were sealed in clean, unprimed 22 caliber long rifle shell cases. The sealed charges, secured to the end of a bakelite rod, were then dropped into a thermostated Wood's metal bath. The surface temperature was taken to be the temperature indicated by a calibrated thermocouple which was taped to the bakelite rod so that the thermocouple juction was within 1/4 in. of the side of the sheil case. The sealed cartridge secured to the bakelite post is shown in figure 1. The cartridge was filled and sealed while attached to the post.

The cartridge-filling operation consisted of placing a 1/8-in. thick teflon disc on the bottom of the cartridge and then pressing 0.08-in. discs of propellant into the cartridge to within 1/8-in. of the open end. A 1/8-in. thick teflon disc was then placed on top of the propellant, and the end of the cartridge crimped with the device shown in figure 2. A hydraulic press was used to lower the crimping device remotely on the filled cartridge in the assembled holder.

This mode of preparing the charge accomplished several things. Gas could not escape from the charge until explosion occurred. This prevented heat from being transported through the sample and out of the sample by escaping gases. The assumption that heat transfer occurs by conduction would have been grossly in error if the samples had not been sealed. If the gaseous decomposition products are autocatalysts, it is again desirable

[1] "Safety Characterization and Processing of a Novel Energetic Propellant" by Mr. J. W. Parrott, Rohm & Haas Company, Redstone Arsenal, Alabama

UNCLASSIFIED

Fig. 1 Loaded cartridge in holder.

UNCLASSIFIED

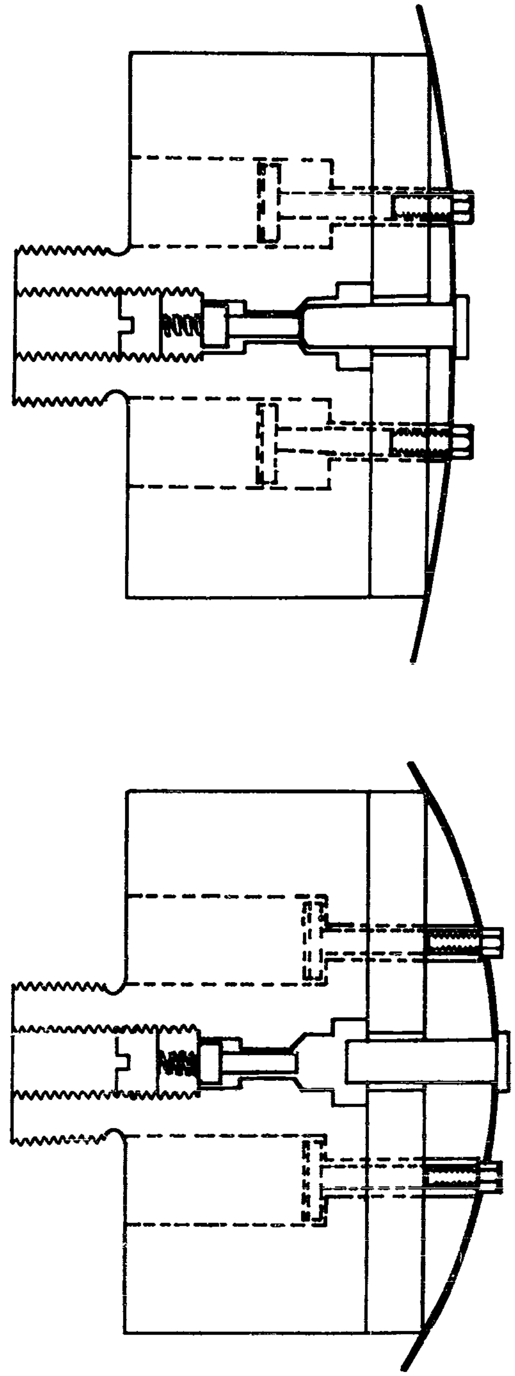

Fig. 2 Cartridge crimping apparatus.

to keep them sealed in the sample if information about the rate of the autocatalytic decomposition is to be gained with minimum effort.

The assumption that the charge was infinitely long, from the standpoint of heat transfer, was also made plausible by the charge preparation method mentioned above. The cut between segments provided some resistance to longitudinal heat flow as did the teflon end plugs. The ratio of length over diameter for the charges was 1.6. A heat-up time of two seconds was subtracted from each explosion time. This was found to be the time which would make the cross-hatched areas in figure 3 equal.

The 1.07-in. diameter charges were cast and cured in a slightly tapered mold to facilitate dropping the charges into a hole of the same dimensions in heated aluminum block shown in figure 4. The taper made centering easier and also allowed air to escape from the hole as the charge was sealed. The seal was a teflon plug held in place by an off-set five pound weight. A horizontal 3/8-in. steel rod between the plug and the weight broke when the sample exploded. The L/D for the 1.07-in. diameter charges was two. The charge was insulated at the top end by the teflon plug and at the bottom end by a 1/2-in. air space. The temperature at the propellant surface was taken to be the temperature indicated by a sheathed thermocouple in the aluminum block. The tip of the sheath was separated from the surface of the charge by 1/8 inch of aluminum. The temperature of the aluminum block was controlled by manually varying the voltage applied to the six symmetrically located 75-watt cartridge heaters. The temperature could be easily maintained to $\pm 1^{\circ}C$.

The 22 cartridges were loaded and crimped behind a shield. The loaded cartridges and the 1.07-in. diameter charges were dropped into the bath and the block remotely. Some of the charges did not explode, either by design or mishap. The 22 cartridge duds were withdrawn from the Wood's metal bath remotely and allowed to cool to room temperature in the bombproof before being discarded. Dud 1.07 in. diameter charges were destroyed by raising the temperature of the aluminum block, again remotely.

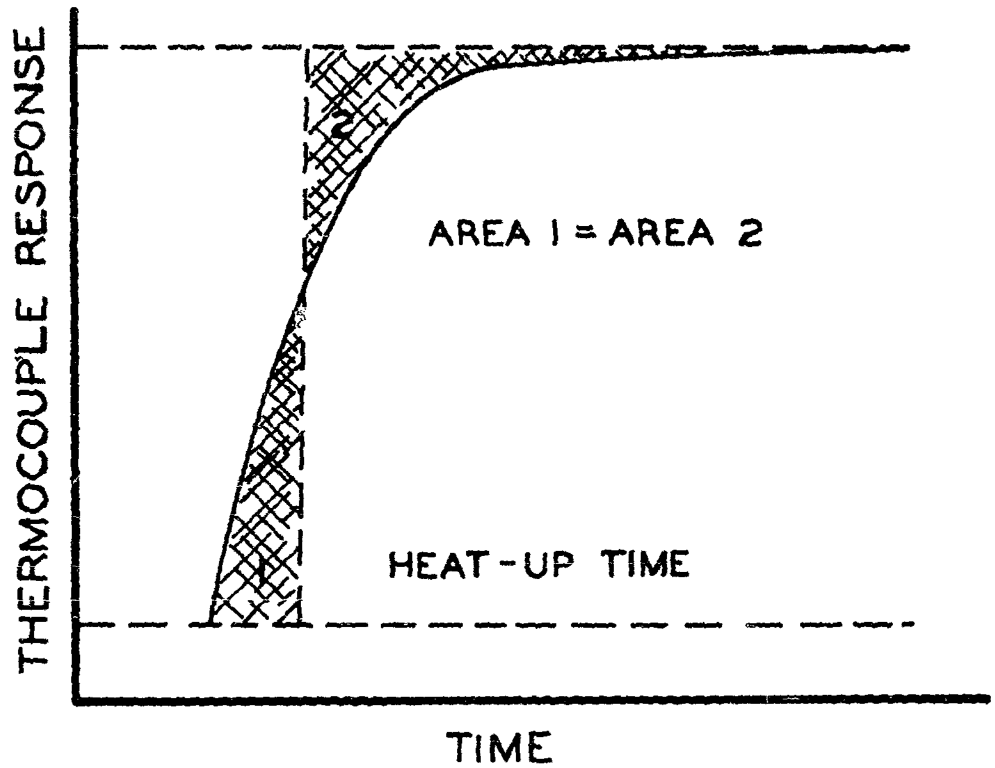

Fig. 3 Determination of heat-up time.

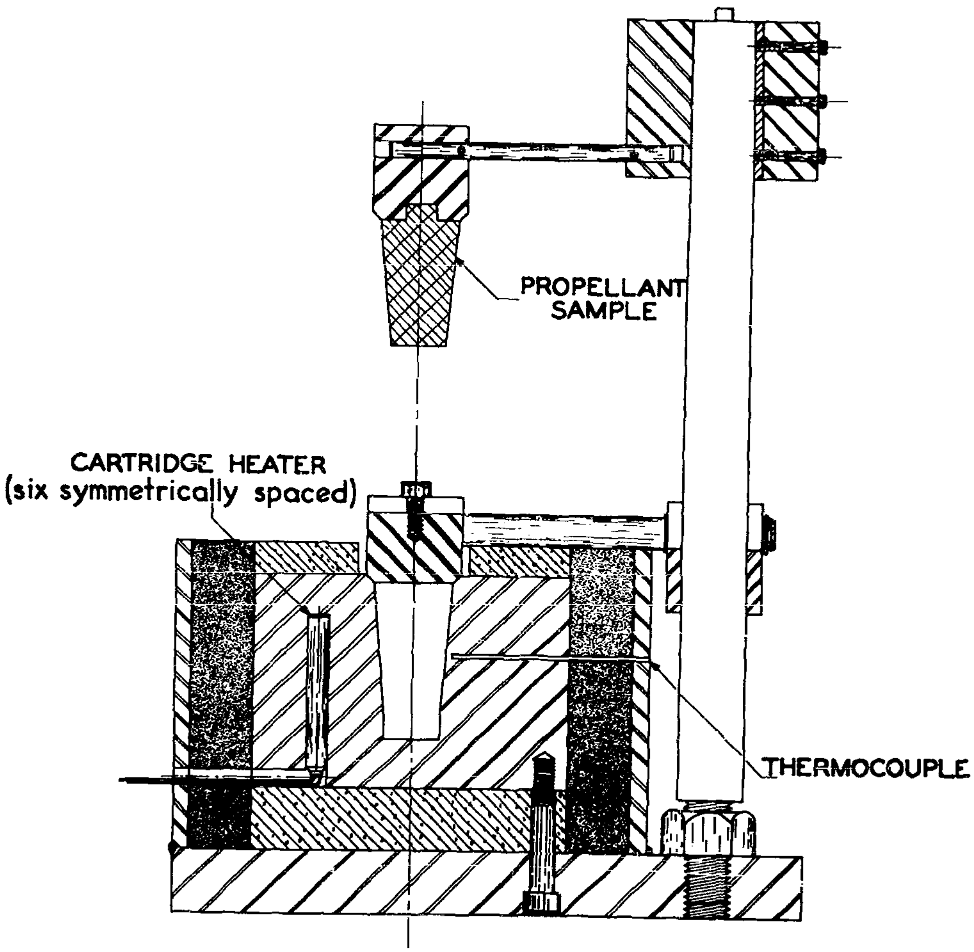

Fig. 4 One-inch explosion time apparatus .

DATA FITTING

The experimental results for SA-1 propellant are presented in figure 5. The fitting of this data to the model was a two-step process. First, the activation energy for the first order decomposition was obtained. This was accomplished by analysis of explosion time data for a sample containing enough aluminum so that autocatalysis by HF and/or F was completely suppressed. The data was plotted on log-log paper (figure 6) with time as the ordinate and $T_m^{-1}-T_1^{-1}$ as the abscissa. The critical temperature is denoted by T_m and the surface temperature by T_1. This plot was then compared with the results of the digital computer calculations of Zinn and Mader (1) for the case of a propellant decomposing by a zero-order mechanism also plotted on log-log paper. The graph of the computer curve was superimposed on the graph of the experimental data. The ordinate of the Zinn and Mader graph is Dt/h^2 and the abscissa is $E(T_m^{-1}-T_1^{-1})$, where E is the activation energy for the decomposition. As a consequence of plotting both graphs on log-log paper, the abscissa shift which superimposes the computer results on the experimental data is a direct measure of E. In this case, the required abscissa shift indicated that the activation energy was 42.5 kcal. $mole^{-1}$. Designating this number as the activation energy for the first order decomposition is justified on the basis that the two cases result in curves that are very close to each other except at temperatures very close to the critical temperature and very far above the critical temperature (2).

Knowledge of the activation energy for the first order decomposition made possible an estimate of the value of one of the four dimensionless constants needed to characterize the explosion time behavior of SA-1 propellant if autocatalysis is significant in determining the rate of decomposition. This

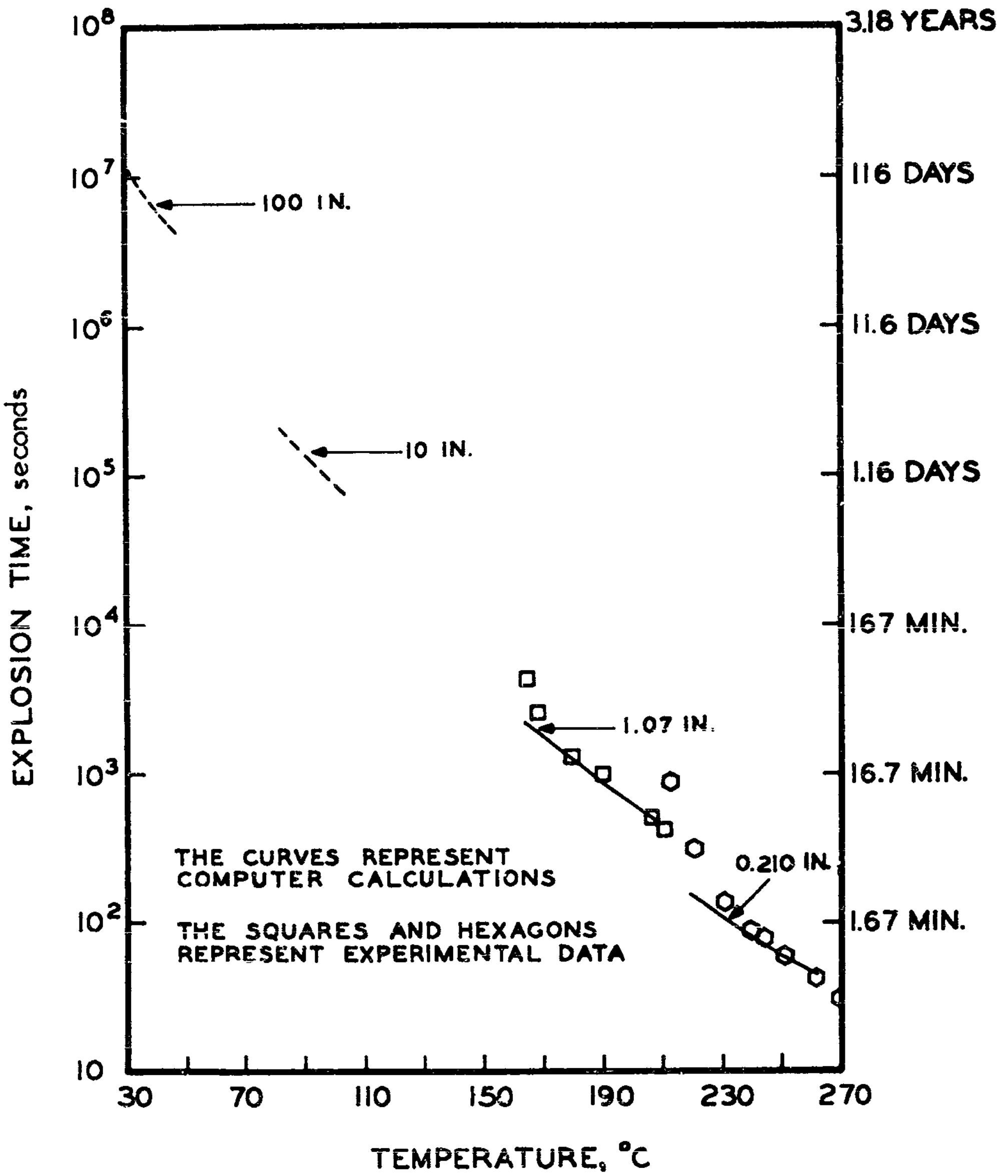

Fig. 5 Explosion time curves for various charge diameters.

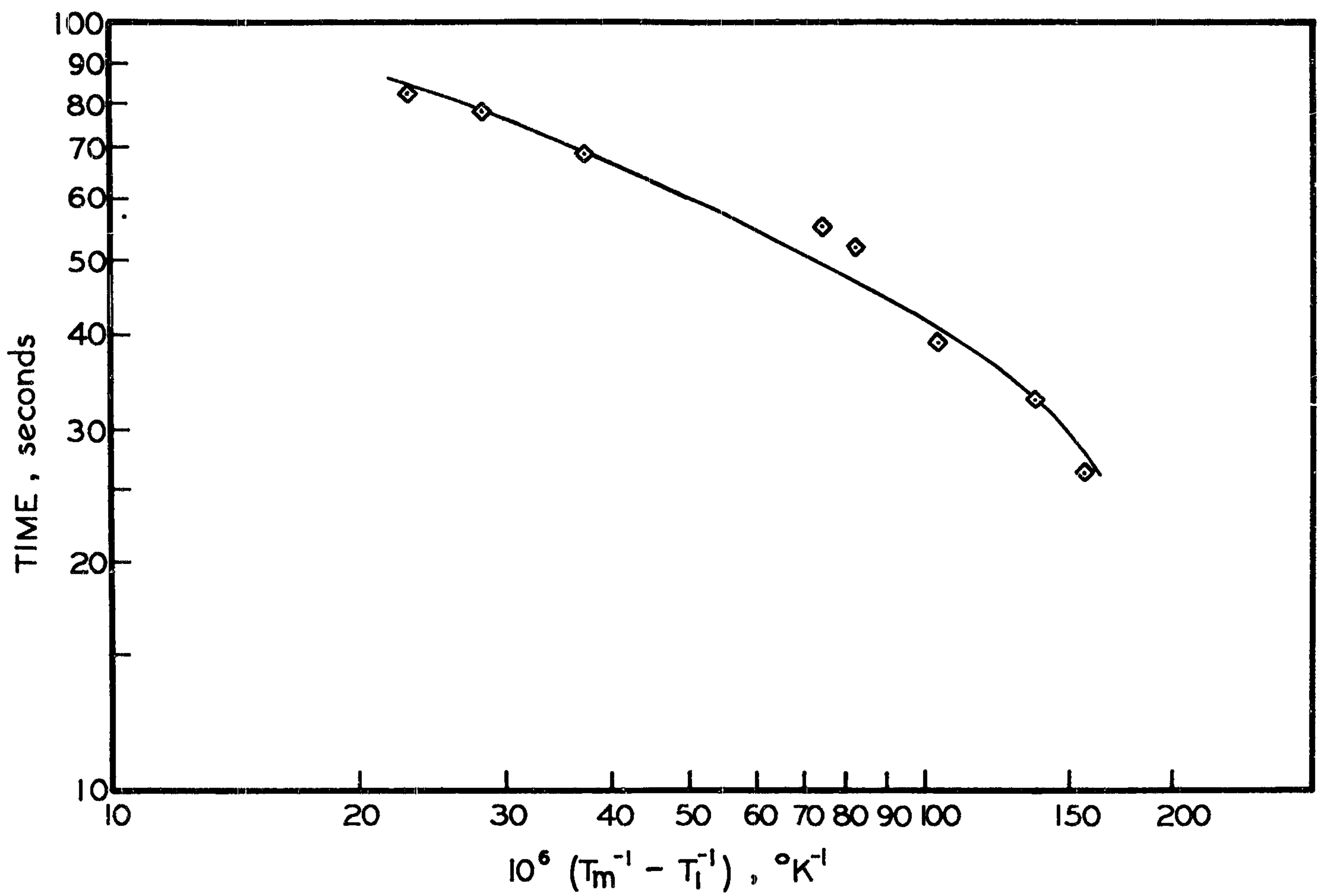

Fig. 6 Fit of zero order computer results to explosion time data for 0.210-in diameter charges of highly inhibited propellant.

constant $\nu = QRC_0/cE_1$, was calculated to have the value 2.631 (10^{-2}) on the basis that Q = 500 cal/g reactant, C_0 = 0.35 g reactant/g propellant, and c = 0.311 cal g^{-1} deg.$^{-1}$. The value for Q was assumed. The value for c was based on Kopp's rule. Experiments to be related elsewhere indicated that the rate of decomposition of the binder determined the length of the explosion times in the temperature range studied. The initial concentration, C_0, was therefore assigned the value of 0.35 g. reactant/g propellant, since the propellant contained 35% binder.

The other three dimensionless constants, $\mu = Z_1b^2/D$, $\kappa = Z_2b^2C_0/D$, and $\lambda = E_2/E_1$, were left to be determined. Since the thermal diffusivity was assumed to 13.9 (10^{-4}) cm^2 sec^{-1}, the unknowns were considered to be Z_1, Z_2, and E_2. The values of these constants were determined by assuming a value for E_2 and then determining, by digital computer calculation, whether or not there were values of Z_1 and Z_2 which would allow the computer to duplicate the experimental results. It was quickly determined that E_2/E_1 had to have a value close to 0.4 before a fit could be obtained. It was also noticed that only one set of values for Z_1 and Z_2 would cause the model to fit the experimental data. The fitting process was tedious but straightforward. The fit presented in figure 5, the curves drawn through the experimental data, was obtained with E_2 = 17.0 kcal mole^{-1}, Z_1 = 4.905 (10^{13}) sec^{-1}, and Z_2 = 4.806 (10^{6}) sec^{-} (g propellant) (g reactant)$^{-1}$. It is believed that the fit at the low temperature end of both curves would have been better if allowance for consumption of autocatalyst had been included in the model.

EXTRAPOLATION

Once the fit had been obtained, the calculation of the expected explosion time-temperature curves for 10-in. and 100-in. diameter charges of this propellant was a simple matter. The dashed curves in figure 5

represent the result of this extrapolation. These curves are only segments of the complete curves for 10-in. and 100-in. charges. In each case, explosions can probably be obtained at slightly lower temperatures and will obviously be obtained at higher temperatures. For present purposes, the author felt that locating the position of the curves was sufficient.

There are several reasons why the extrapolation should be viewed with some skepticism. First of all, consumption of autocatalyst by the aluminum, or other natural inhibitors in the propellant, was not included in the model. There is, then, the possibility that at some lower temperature autocatalyst might be consumed faster than it could be generated. This would mean that the present extrapolation gives too bleak a picture of the stability of large charges of this propellant. On the other hand, solvolytic degradation of the propellant due to water or impurities may become the rate-controlling heat-producing process at lower temperatures. In this case it is possible that large charges of propellant may be less stable than the present extrapolation suggests. It is clear that an extrapolation of the type described above serves only as a guide-line for further work. For instance, the extrapolation should be checked with 10-in. diameter charges.

FUTURE COMPUTER PROGRAMS

The present computer program may be easily extended to include the case of the cylindrical charge with a circular perforation centered on the centerline of the charge. A program for the case of a star-shaped perforation is possible. The inclusion of this extension of the program is being contemplated. Allowance for diffusion of decomposition products

through the propellant is being included in a program presently being developed. A part of the present program, which was not used, allowed for a thermal contact resistance between propellant and case, for heat transfer through the case, and for heat transfer from the case to the surroundings.

It is apparent that a program should be obtained which would handle the data-fitting process automatically. The trial- and -error process reported above was instructive but needlessly wasteful of time.

CONCLUSIONS

Explosion time-temperature curves can now be analyzed for the effect of autocatalysis, an all too common mode of propellant decomposition. Digital computers have made this possible. Even though the data is obtained over a wide temperature range, digital computer extrapolation from small scale data to full scale behavior should be viewed with skepticism unless there is independent information about the completeness and accuracy of the mathematical model used in the calculations.

The relationship between thermal stability and charge diameter is strongly dependent on the mechanism and activation energies for the decomposition processes. As a consequence, it is unsound to base estimates of the thermal stability of a large charge of a new propellant solely on the basis of a comparison of small scale thermal stability data for this propellant with small scale thermal stability data for a well characterized propellant. This is particularly true if the decomposition processes in the new propellant involve unfamiliar chemistry.

[1] Zinn, J. and Mader, C. L., J. Appl. Phys., 31, 323 (1950).
[2] Zinn, J., private communication.

Dr. Amster: I missed one point on your talk. How did you decide th. this reaction was actually auto-catalytic?

Dr. Booman: Memory experiments for one thing, for another thing, if you put the sample in a hot bath and then take it out, the material remembers how long it was in the hot bath and the explosion time next time is shorter. Another item has to do with the fact that propellants that decompose or explosives that decompose zero order, the maximum explosion times that are observed in terms of reduced units are about three. For this reason the reduced time unit is diffusivity time divided by the square of the radius. Propellants that decompose zero first order just don't have explosion times longer than three in terms of these reduced units. This propellant has explosion times of range up to 10, 12, and 13.

Mr. Saffian: Have you investigated this technique in terms of cycling a sample between two temperature limits to see if there - you just said the propellant remembers - is there any hysteresis effect or anything of that sort? Can you account for that quantitively?

Dr. Booman: I haven't. I could, by taking the final composition - let's put it differently, giving the computer a starting condition and then stopping the computer at a given time and noticing what the concentration distribution of auto-catalyst and an explosive ingredient was at each point in the charge and then taking these as initial conditions for another computer run and seeing how long it takes for the computer to explode in the second run. This can be done, I haven't done it.

Mr. Couch: You used the word explosion, could you define that?

Dr. Booman: By explosion, I mean a runaway reaction. It's obvious that these equations couldn't tell you whether a sample was deflagrating or detonating.

Mr. Couch: You meant reaction then actually.

Dr. Booman: I meant a reaction or going awfully fast.

A THERMAL HAZARD STUDY OF HIGH-ENERGY PROPELLANTS FOR SAFE STORAGE AND USE(U)

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U. S. Naval Ordnance Test Station
China Lake, California

When the size of solid propellant grains was increased to diameters of 54" and larger, a new hazard was introduced. This new hazard, oddly enough, arose because of the practice of requiring that the rocket motor be temperature conditioned, and maintained within narrow limits. The requirements for temperature conditioning must consider maintaining the integrity of the grain and other components within the rocket system. This requirement must now further consider the size and composition (high energy) of the propellant grain. A temperature conditioning apparatus is not absolutely reliable and on occasions may malfunction, and extreme overheating of the motor may occur. Cases are on record where malfunctioning temperature-conditioning units (through either mechanical or human failure) have exposed heated rocket motors to temperatures far beyond the temperatures encountered during direct exposure to desert sunshine. An incident, for example, aboard the USS MEREDITH (DD-890) occurred in December 1961 with an ASROC rocket motor, Mk 1 Mod 0, which inadvertently ignited in Cell No. 3 of the launcher. The rocket motor case had ruptured and the propellant burned in the cell. The Mk 44 torpedo payload and the missile airframe remained in the launcher. Prompt ship's action with firefighting equipment was taken so that no further ignition occurred with the other missiles in the launcher. Tests performed at a later time on the heat exchanger at the Philadelphia Naval Shipyard showed evidence of defects which permitted steam to leak from the primary side into the secondary side. The steam regulator value which was supposed to maintain a temperature of 112°F maximum in the liquid on the secondary side also was inoperative. It also was reported that the temperature sensors from two cells were damaged, indicating that they had been exposed to temperatures over 250°F. At temperatures of this order the propellant was literally cooked-off as will be discussed later. This mishap, and others, have emphasized the need to study all rocket motors requiring temperature control and establish the critical temperatures above which they will deflagrate or explode.

A study has been underway at the Naval Ordnance Test Station involving methods for predicting thermal hazards from exothermic heat (Ref. 1, 2). The study covers work on double-base and composite type propellants including several propellants now in use or expected to be

put into use. Each of these propellants, regardless of its type, exhibits certain chemical and physical properties that are unique for that propellant. These particular properties, which include density, thermal conductivity, activation energy, frequency factor, heat of reaction, and heat capacity, have been determined from propellant samples by laboratory methods. After determination, these various properties are combined through involved mathematical treatment and are used to determine certain thermal characteristics which relate time and temperature with size and shape of a propellant grain. Therefore, the critical temperature, T_m, for practical purposes, is defined as the environmental temperature where, for a given shape and size of propellant grain, the heat generated by chemical action within the grain is in balance with the heat being conducted through the propellant to the surrounding atmosphere. At environmental temperatures exceeding the critical temperature, self-heating will occur. Self-heating can lead to the destruction of the grain by deflagration or explosion if permitted to progress too far. The mathematical treatment of critical temperature, provided the rate of decomposition is controlled by a statistical process, allows the temperature within the propellant to be described by the Frank-Kamenetski relationship:

$$\rho c \frac{\partial T}{\partial t} = \lambda \nabla^2 T \ X \ \rho Q A E^{-E/RT} \quad \text{(Ref. 3 and 4)}$$

Which under steady state conditions where the temperature is constant gives: (Heat generated equals heat lost to the surrounding atmosphere).

$$\lambda \nabla^2 T + \rho Q A E^{-E/RT} = 0$$

and integrated to give the T_m as defined above:

$$T_m = \frac{E}{2.303\ R\ \log\left(\frac{\rho a^2\ QAE}{RT_m^2\ \delta}\right)}$$

where

C - heat capacity, cal/g-°c
E - activation energy, cal/mole
Q - heat of reaction, cal/g
R - gas constant, 1.987 cal/mole - °K
T - temperature, °K
t - time, sec
A - collision frequency, sec^{-1}
λ - thermal conductivity, cal/cm - sec -°c

ρ - density, g/cm^3
^{2} - Laplacian operator of vector analysis
a - radius, cm
δ - shape factor

Description of Problem

A study of thermal hazards has been underway involving methods for predicting these thermal hazards caused by exothermic heat (Ref. 2). This internal heat generation (self-heating) by chemical action, is temperature-rate dependent and therefore increases as the storage temperature increases. Since the heat content is dependent on thermal conduction in the propellant and distance of the thermal path, the size and shape of the grain will effect the temperature-time relationship. The equation previously determined for critical temperature considers these factors to relate "temperature-time" history with a given "size-shape" of propellant grain. After determination of these various properties in a propellant system, and calculation of the critical temperature, a temperature range with a safety factor can be established for a particular size-shape of a propellant grain. The different factors that effect the thermal stability in a propellant grain can be seen in the evaluation of the critical temperature. A plot of log propellant weight as L/D equals one vs the reciprocal critical temperature demonstrates how different chemical and physical properties can affect the critical temperature (Fig. 1). The lines are for a double-base, a composite and a nitronium perchlorate as predicted where the points are experimental results. The points fall within ±10% of the predicted value.

Comments and Cautions

The techniques used show not only a temperature-time and a size shape relationship but also that all four factors are related mathematically through the different chemical and physical properties involved in each propellant system. These factors are brought out as with ASROC propellant from which a laboratory thermal stability study predicted a critical temperature of about 190°F. The following table illustrates the effect of storage above and below the experimental critical temperature of 195 ±5°F.

ASROC Propellant Grain Reactions to Storage Above and Below the Critical Temperature

Oven storage temp. °F	Center of grain temp. °F	Exotherm of center of grain °F	Time to defla-gration hrs.	Remarks
165	---	0	---	Internal cracks developed 10 days.
171	172	1	---	
183	186	3	---	
190	196	6	---	
....				Critical temp. est. 195 ±5°F
204	---	deflagration	94.6	
222	---	"	46.3	
250	---	"	31.2	

A similar thermal stability study was performed on a high energy propellant which in this case was a coated nitronium perchlorate (NP) - polyurethane polymer propellant. A value of 20 Kcal/mole was obtained for the activation energy at NOTS which compares with the activation energy of 16.7 Kcal/mole obtained by Thiokol with similar NP propellants (Ref. 5). Some examples of DTA peak values for various coated NP-polymer propellants are listed below:

	DTA ∅ = 10°C/minute		
	Approximate Temperature (°F)		
Binder	Peak	Ignition or Explosion	
Polymethylmethacrylate	228.2	251.6	(Thiokol)
Ethylene - Maleic acid	194.0	242.6	"
PolyC_9Fluoroalkyl Acrylate	194.0	228.2	"
Ethylene-Maleic Anhydride	120.0	222.8	"
Polyethylene	-	217.4	"
Polyurethane polymer	260.0	-	(NOTS)

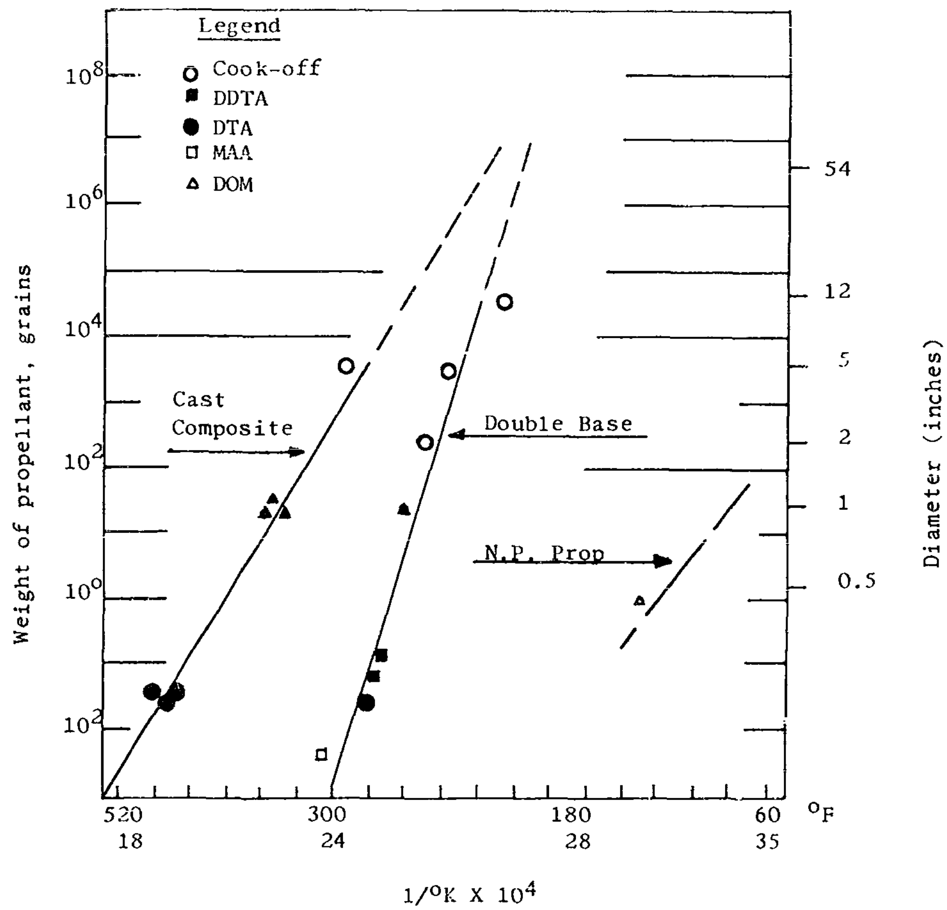


Fig. 1. Propellant weight vs. critical temperature for cylinders L/D ratio equal to 1.

Mr. Weintraub: I noticed on your chart where you have cook-off you have for polybutydiacrylic acid, the two points you had for the PDAA - now, when you say cook-off, do you mean the deflagration-detonation transition, or do you just mean auto-ignition?

Mr. Pakulak: This is a sample where the sample is totally consumed that usually occurs within seconds. In other words, the sample is put into a preheated oven and the sample is supposed to be at ambient temperature, now this is a hard thing to define because we have ambient temperatures from -68° to $180^{\circ}F$. But approximately 70 to 80° the sample is introduced into the preheated oven and we have a warm-up time that is recorded and sometimes a small amount of exothermic heat which we record and sometimes this is displayed, sometimes not, and this goes on and all of a sudden cooks off and the time to cook-off is then timed to disintegration.

Dr. Macek: What is the source of your chemical kinetic data for your computation for the theoretical lines?

Mr. Pakulak: On the critical temperature where we sent it into computer, we tried to make as much as possible from actual laboratory or thermal analysis. The activation energy is plotted by a method developed by Kissinger which is called the Variable Heating Rate Method as applied to differential thermal analysis and we vary the heating rate, maybe anything from, we used to go down to about a half degree farenheit, but I believe we're now about 1 to $2^{\circ}F$. with our new equipment and we can go clear up to about $30^{\circ}F$. per minute.

Dr. Macek: These are not then any vacuum test or anything like that?

Mr. Pakulak: Oh no, we could but they are not.

SAFETY CONSIDERATIONS IN OPERATING SOLID PROPELLANT MIXERS

by
R. O. Martin
Longhorn Division
Thiokol Chemical Corporation

This presentation relates to the experience gained by Thiokol Chemical Corporation's Longhorn Division, Marshall, Texas in handling major hazard areas which are common to the industry in mixing solid propellants.

Our experience in propellant mixing at the Longhorn plant covers approximately seven years. During this time we have designed and procured equipment for three complete new mixing complexes. We also have rehabilitated one 200-gallon horizontal mixer and made numerous other modifications and improvements.

Today's discussion will be confined to safety problems inherent in design features of vertical mixers and horizontal submerged gland mixers. The latter are discussed relative to two specific problems: The first is blade and bowl clearance where contact between parts having relative motion is a consideration; the second problem concerns packing glands.

Vertical mixers are discussed briefly in reference to studies of design drawings rather than in reference to actual experience.

Ignition temperature--the final condition which will cause an incident--is of basic importance. Two of the significant factors which create ignition temperature, pressure and friction, are of primary concern in considering problems and solutions of solid propellant mixer operations.

<u>200-Gallon Horizontal Submerged Gland Mixers</u>. At Thiokol-Longhorn we use the horizontal sigma blade 200-gallon mixer. With these mixers, the clearance between blade and bowl is a major safety problem. At several critical points it is possible for mixer components to contact directly or through the agency of foreign material. If these critical clearances are not adequate, contact can occur along the bowl troughs, at the bowl ends along the path of blade rotation, and at the blade shafts where they pass through the bowl ends.

The mixer blades present a special problem in that they contract and expand as heat is applied to control propellant temperature during the mixing cycle. The quantity of heat applied is controlled by blade

cores through which steam and cold water can pass. To compensate for lengthwise expansion and contraction, the blade shaft and bearing adjacent to the gear case are free to move along the length of the bearing housing. At the opposite end, the longitudinal position of the blade, nominally fixed, can be adjusted by shimming.

Temperature changes have their greatest effect on clearances at the bowl end. These clearances have been measured to determine the maximum effect of temperature change. Exhibit One shows the clearance dimensions before and after a temperature change. The larger clearances were measured with the bowl and blades at 84°F; the smaller clearances were measured with the bowl at 44°F and the blades at an average temperature of 155°F. This temperature change reduced clearance by as much as .070". As noted on the exhibit, temperatures along the blades were not the same. It should be noted that this condition contributes to blade distortion.

Manufacturing tolerances also contribute to the clearance variations, notably between the blade shafts and the bowl ends where the shafts pass through. During reassembly of one Thiokol-Longhorn mixer, the holes through the bowl ends were found to be mislocated approximately .015" relative to the center of blade shaft rotation. This condition produced a clearance of .015" at one point and .045" at a point 180° away.

Clearances within the bowl also are affected by blade and shaft distortion which come from uneven temperatures and deflections due to working loads. An experiment was conducted to determine the amount of shaft deflection under torsional loads. Exhibit Two shows, schematically, the set-up used and the dial indicator readings which were obtained. The readings, ranging from minus .006" to plus .020" are not considered entirely accurate. There was no provision for measuring the influence of lathe bed deflection.

The mixer blades are overdesigned to provide rigidity and while the probability of metal fatigue consequently is reduced, this factor cannot be ignored entirely as a safety consideration.

At the present time, solutions to the safety problems posed by blade-to-bowl clearances in our horizontal mixers must be derived empirically. There is no experimental data, experience history or other scientific basis for defining minimum blade-to-bowl clearances which are consistent with safety.

At Thiokol-Longhorn we have arbitrarily increased clearances to provide adequate safety but do not have data which would indicate if mixing efficiency has been decreased and, if so, what measurements might be changed without reducing factors. Current specified minimum clearances are .095" along the bowl troughs; .095" between bowl ends

and blades (at the end where their relative positions are fixed); a 125" between bowl ends and blades (at the end where longitudinal movement is allowed as temperature change compensation); and .070" between the blade shaft and the bowl ends.

These clearances have been obtained by in-plant machining of mixer components as required.

Feeler gages are used at frequent intervals to check all clearances. Blade to bowl clearances are gaged daily, prior to mixing operations. The annular clearance between the blade shaft and bowl end, however, is accessible only during packing replacement and measurements therefore are restricted to the time this operation is performed.

If gage readings show any clearance is less than the specified minimum, the mixer is not operated until the cause of the anomaly is found and appropriate corrective action has been completed.

Deflection and distortion of the mixer blades is minimized by avoiding heat transfer through the blade except when the heat is required to maintain a specified propellant mix temperature.

Shaft ports through the bowl ends have been rebored as required to provide accurate alignment.

Dye penetrant tests and radiological inspections are conducted after each 1200 hours of mixer operation as a means of detecting metal fatigue and other mechanical failure in the blades. At this time the mixer is disassembled for a complete components inspection.

In the introduction to this paper it was stated that principal problem areas in the safe operation of horizontal mixers would be discussed. The problems incident to clearance for moving parts has been commented upon and brings us to the more critical second area, namely, packing glands.

Horizontal mixer packing glands (or stuffing boxes) are of conventional design and are sized to accommodate six rings of 7/8" square packing for the blade shaft which has a 6½" diameter. When the packing is forced against the shaft by sealing pressures, a considerable area of friction and a natural source of heat are created. At the time the Thiokol-Longhorn mixers were purchased there was no experience factor extant to indicate that the equipment should incorporate a device for monitoring the heat being generated.

High temperatures generated at the shaft surface adjacent to the propellant are of critical importance safetywise; design features of the horizontal mixer have made it impossible to date, however, to devise

a satisfactory temperature monitoring device to operate at this crucial point.

Other factors which contribute to the packing gland temperature control problem include: (1) Packing materials which vary in their abrasive characteristics and their head absorption capabilities. (They also may include tramp metal.) (2) Surface finish and surface speed of the shaft affect operating temperature.

As the packing glands are located between the actual shaft bearings, they act somewhat as supplemental bearing surfaces in resisting transient forces resulting from shaft deflection and distortion. (The deflection and distortion, it will be recalled, are created by working loads, by the expansion and/or contraction, and by uneven temperature distribution.) Deflection and distortion cause the shaft to rotate eccentrically and this movement displaces packing which, in turn, prevents retention of an effective propellant seal. It is probable that the end result of this induced shaft eccentricity is a pumping action in the gland.

It is appropriate at this point to examine Exhibit Three which shows the annular space between the shaft and bowl end adjacent to the blade hub. As designed by the mixer vendor, this space is about ½" in length and is rendered inaccessible by the blade hub for inspection and cleaning. Propellant can lodge and cure in this space to become an additional hazard in an already critical zone. As was indicated previously, it is practical to clean this space only when the packing is replaced.

While most of us who have had experience with horizontal mixers would agree, no doubt, that there is no ideal packing gland arrangement, I would like to point out some modifications which we at Thiokol-Longhorn believe make the operation of this equipment safer.

First, blade shafts in contact with packing now have an 8 microinch surface finish in contrast to the 32 microinch surface finish previously evident; this modification reduces the friction coefficient.

Second, blades and bowl ends have been modified as shown by Exhibit Four. Diameters through the bowl ends have been increased to provide a .075" minimum annular space between the shafts and bowl ends.

Third, the blade hubs and the ports through the bowl ends have been chamfered to eliminate the propellant trap and, at the same time, provide space for inspecting and cleaning the end of the gland. In addition, the blade hub chamfer provides a wiping action at its termination and tends to keep propellant away from the gland.

Fourth, packing is soaked in liquid polymer which provides some lubrication and appears to retard penetration of contaminants into the

packing. The braided commercial grade jute presently being used as packing passes a rigid radiological inspection after being soaked in the polymer and before being installed; packing is replaced after the mixer has been in operation for 30 hours.

Fifth, as shown by Exhibit Five, the packing glands have been modified to incorporate a liquid purge system and a temperature monitoring system. A lantern ring is positioned between packing rings to provide a reservoir and passage for the purge medium and thermocouple. A liquid polymer is used as the purge medium and is forced through the gland into the mixer bowl by a slight positive pressure. Flow rate is five to ten ounces per hour for each gland and the polymer lubricates the gland as well as preventing contaminants entering from the mixing bowl. (The liquid polymer used as a purge must, of course, be compatible with the type of propellant being mixed.) The temperature monitoring system senses heat generated adjacent to the blade shafts at the lantern ring and records temperatures in the remote control station. Mixer controls are interlocked with the monitoring system to provide an automatic shutdown should the indicated gland temperature reach 180°F.

While the foregoing modifications and procedures already are being used at Thiokol-Longhorn, Exhibit Six shows a different packing gland arrangement which is about to undergo trial tests. It will be noted that this design incorporates a quick change cartridge containing lips seals and a lantern ring. If this design operates successfully, it will have the great advantage of eliminating packing and permitting frequent, economical cleaning and replacement of seals.

Exhibit Seven shows an experimental gland unit which has been designed and fabricated. This unit provides variable shaft speeds, adjustable shaft runout, and temperature sensing at the surface of the shaft in the end of the gland adjacent to the propellant. Experiments are to be conducted to determine the effect of shaft speed on shaft temperature when different types of packing are involved. These tests also will provide data on the effect of shaft runout on gland temperature and leakage, the requirements for air purge, improvements for liquid purge and performance of lip seals.

Perhaps the most significant commentary on Thiokol-Longhorn efforts to solve packing gland problems is that we have been led to a consideration of vertical mixers.

Vertical Mixers. Thiokol-Longhorn has studied two vertical mixer designs in some detail. The Baker-Perkins design is discussed in this presentation because we have accumulated somewhat more information concerning the operational problems it presents.

Exhibit Eight shows the Baker Perkins vertical mixer. Submerged glands are eliminated and several advantages in propellant mixing are

indicated. There are, however, some pertinent safety problems involved in the equipment's design features. Six problems which have been examined by Thiokol-Longhorn are:

1. Structural rigidity at the bowl flange may be inadequate to maintain a true diameter where the bowl mates with the mixer.

2. The telescoping joint which aligns the bowl with the mixer is exposed to propellant and therefore is undesirable.

3. Working loads imposed on the cantilevered blades produce a greater bending moment than in the horizontal mixer; clearances, therefore, are more critical.

4. The lower planetary bearing is a friction bearing and therefore is undesirable.

5. The seals provided at the shaft bearings and the planetary bearing may be inadequate in relation to dust and gases.

6. The total area of vent openings is not sufficient for adequate venting of gases in the event of a fire.

Thiokol-Longhorn is currently proceeding with plans to install a Baker Perkins vertical mixer in a new mixing facility and modifications of the equipment have been scheduled to improve design features associated with the aforementioned problem areas. These changes include:

1. The bowl flange will be modified to stabilize the mating diameter and provide a more desirable alignment and sealing method.

2. Blade to bowl clearances will be increased from 1/8" to 1/4" nominal.

3. The lower planetary friction bearing will be replaced with a ball bearing.

4. Air purge to the blade shaft bearing seals and the planetary bearing seals will be provided.

5. The vent area will be increased and a different method of covering the vent openings will be devised.

<u>Summary</u>

Optimum solutions to all safety problems in the operation of solid propellant mixers have not, of course, been found. Significant improvements, however, certainly have been made.

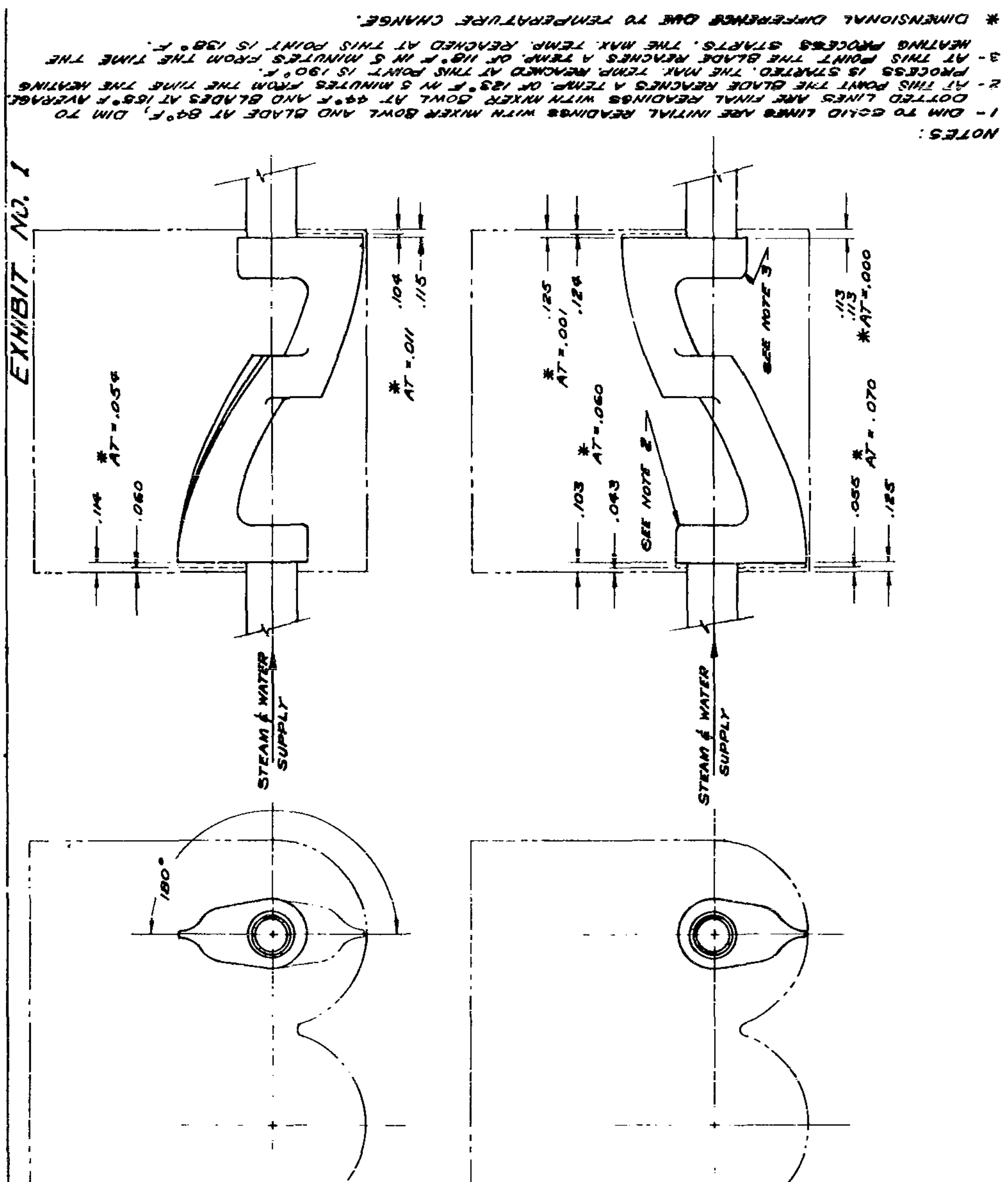
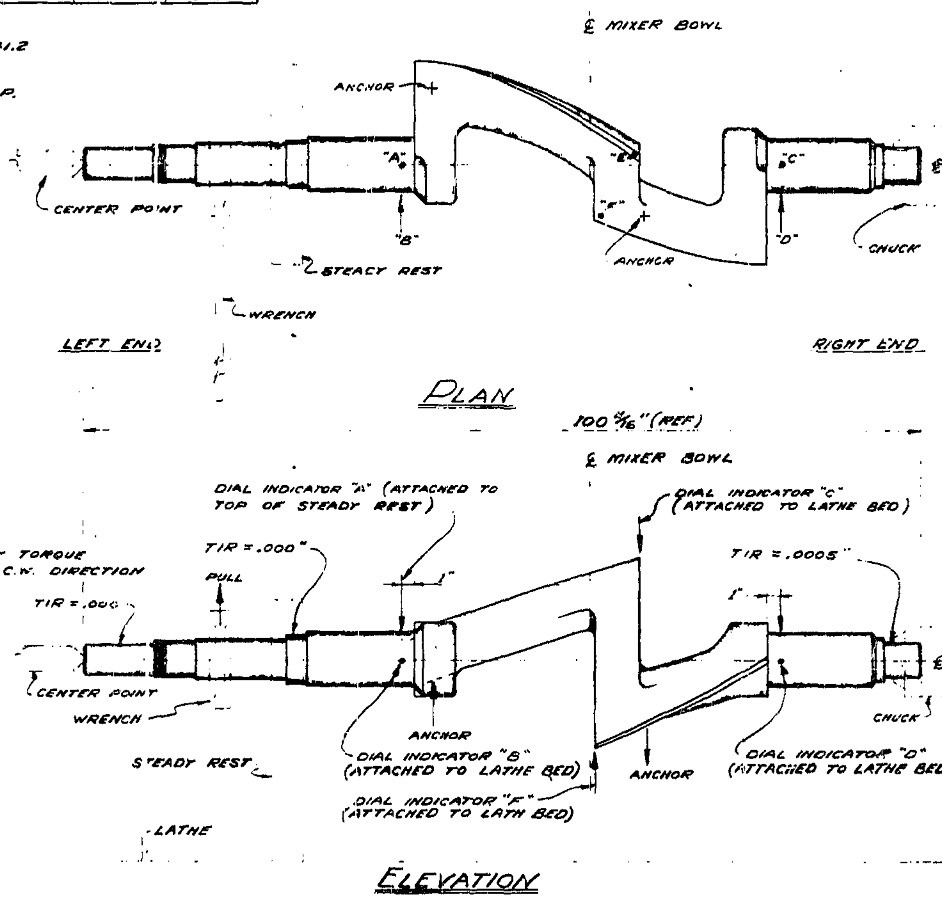


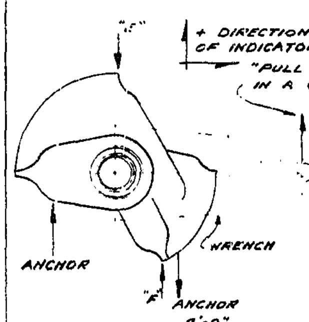
EXHIBIT NO. 1
NOTES:
1 - DIM TO SOLID LINES ARE INITIAL READINGS WITH MIXER BOWL AND BLADE AT 84°F, DIM TO DOTTED LINES ARE FINAL READINGS WITH MIXER BOWL AT 44°F AND BLADES AT 165°F AVERAGE.
2 - AT THIS POINT THE BLADE REACHES A TEMP. OF 123°F IN 5 MINUTES FROM THE TIME THE HEATING PROCESS IS STARTED. THE MAX. TEMP. REACHED AT THIS POINT IS 190°F.
3 - AT THIS POINT THE BLADE REACHES A TEMP. OF 118°F IN 5 MINUTES FROM THE TIME THE HEATING PROCESS STARTS. THE MAX. TEMP. REACHED AT THIS POINT IS 138°F.
* DIMENSIONAL DIFFERENCE DUE TO TEMPERATURE CHANGE.
.114
.060
* AT = .054
* AT = .011
.104
.115
.125
.124
* AT = .001
.103
.043
* AT = .060
SEE NOTE 2
SEE NOTE 3
.113
.113
* AT = .000
.055
.125
* AT = .070
STEAM & WATER SUPPLY
STEAM & WATER SUPPLY
180°

EXHIBIT NO. 2

PULL	DEFLECTION SCHEDULE — DIAL INDICATOR A	B	C	D	E	F
1000#	+.006"	-.002"	.000"	.000"		
2000#	+.0175"	-.005"	+.005"	-.002"		
2100#	+.020"	-.006"	+.006"	-.003"	+.015"	+.012"

NOTES:
1. — 2100# IS THE EQUIVALENT OF 41.2 H.P. @ 31 RPM.
2. — BAKER PERKINS CALCULATED BLADE DEFLECTIONS AT 47.5 H.P. & 31 RPM ARE:
RIGHT STUFFING BOX .000"
LEFT STUFFING BOX .005"
CENTER DEFLECTION .016"





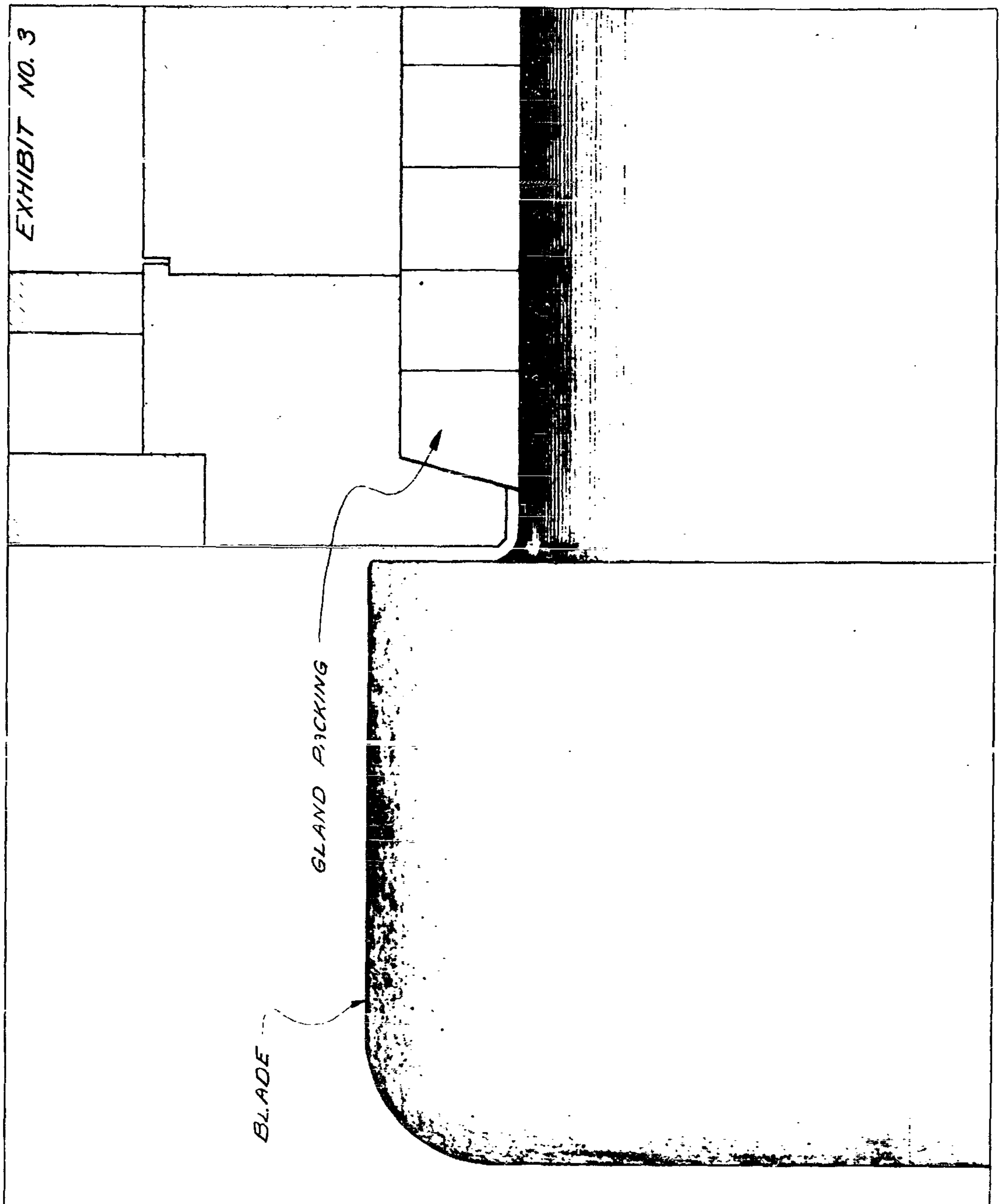


EXHIBIT NO. 3
GLAND PACKING
BLADE

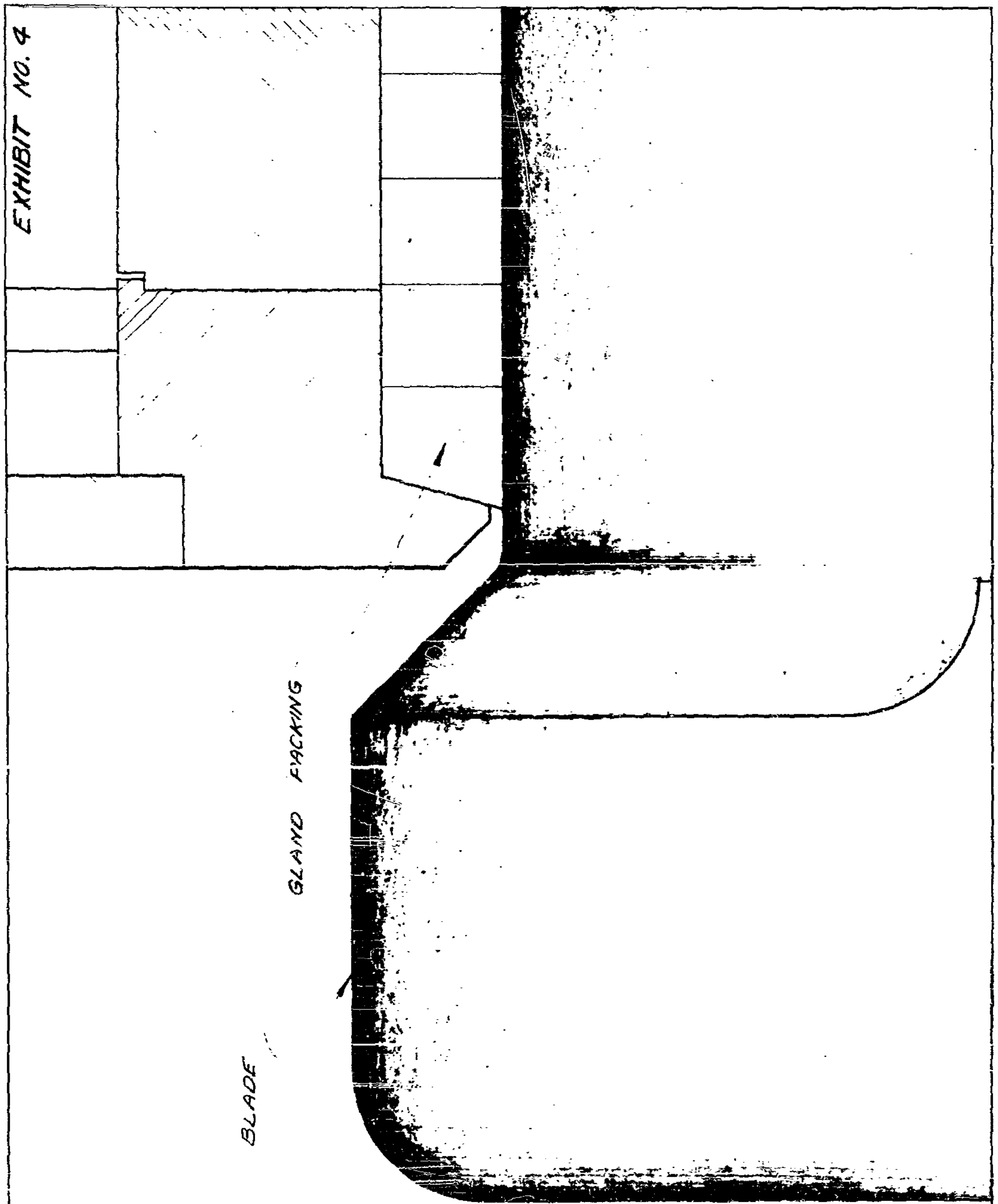


EXHIBIT NO. 4
GLAND PACKING
BLADE

EXHIBIT No. 5

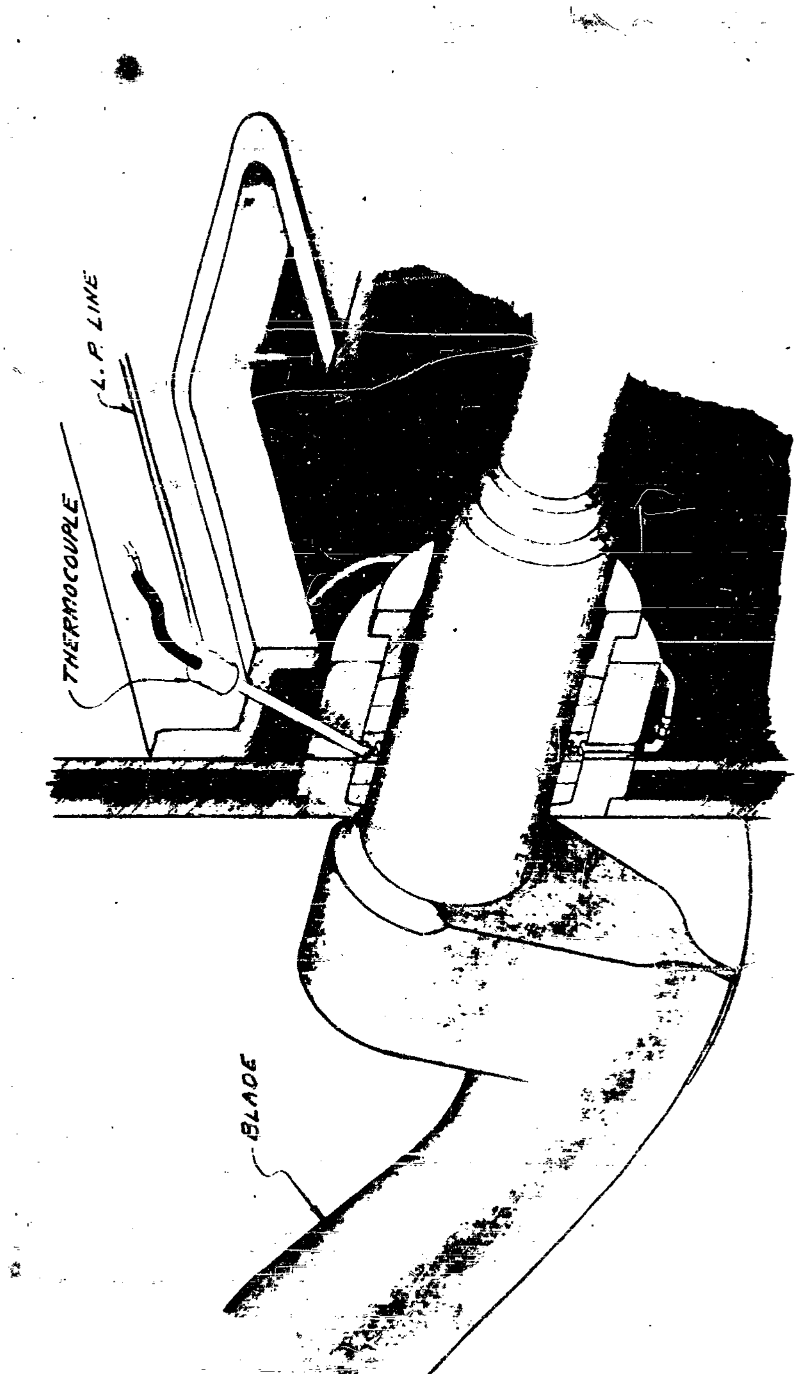


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EXHIBIT NO. 6

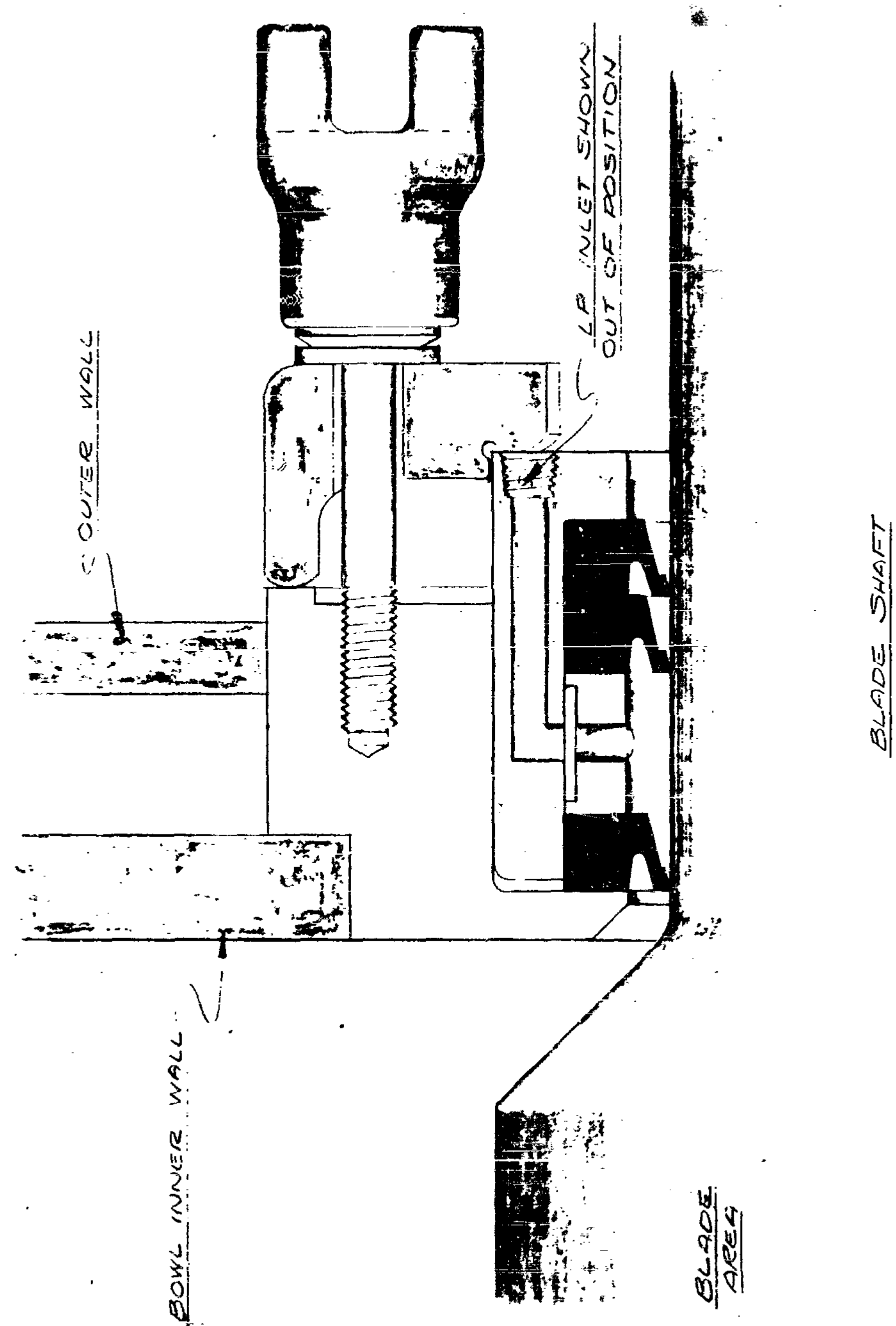

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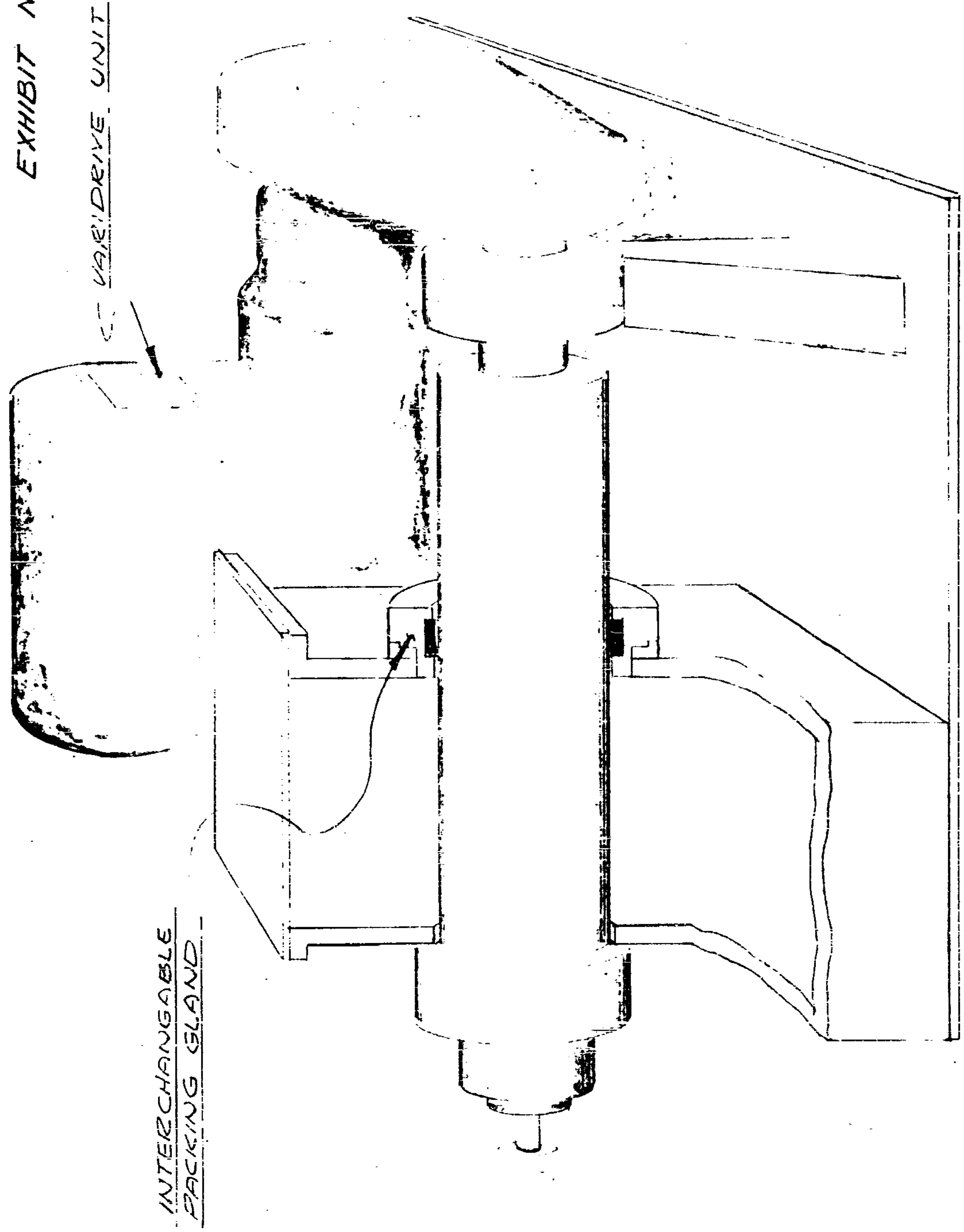
EXHIBIT NO. 7



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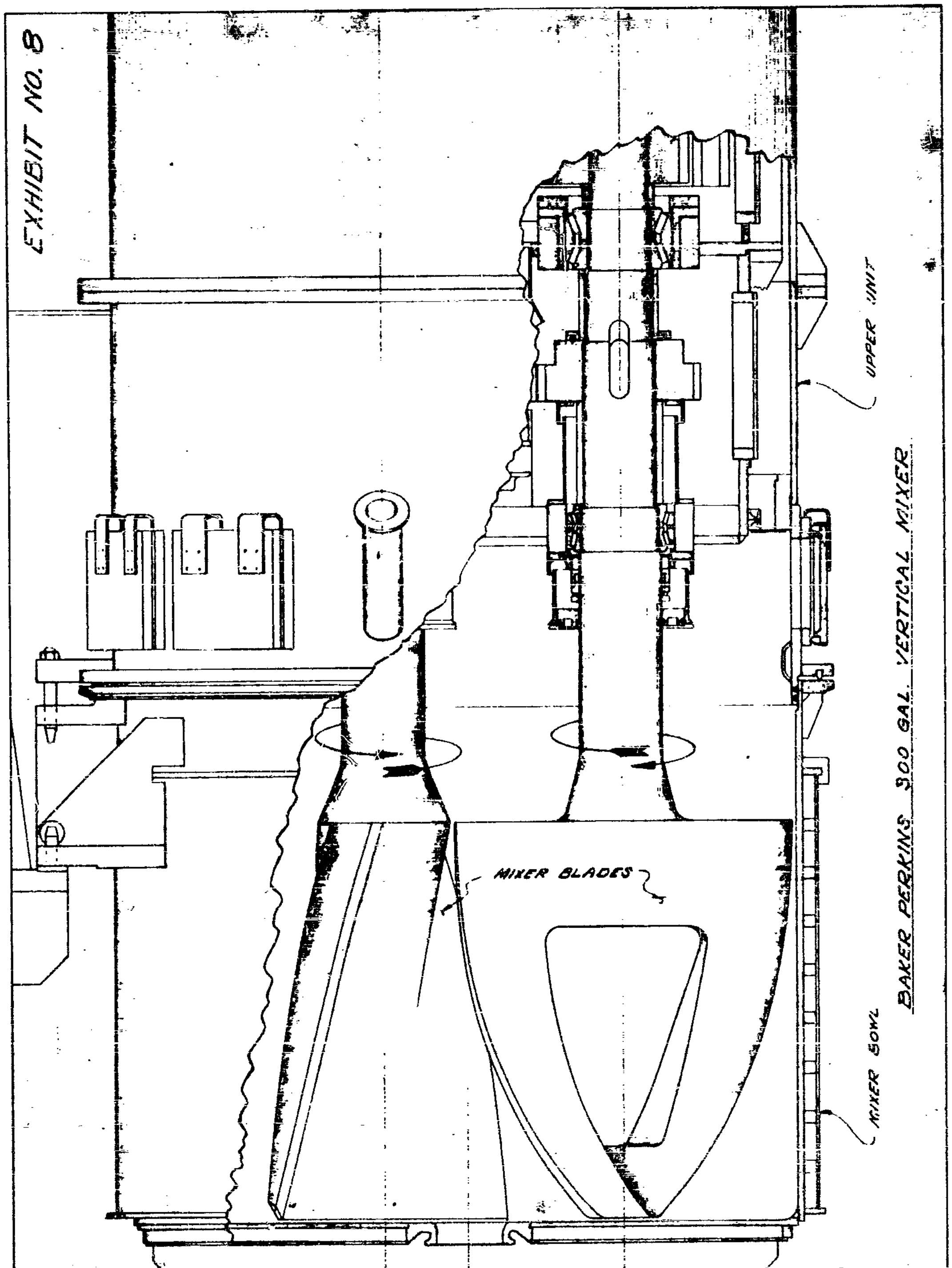

UNCLASSIFIED

Safer packing glands for horizontal mixers have been provided through the use of lantern rings, a liquid purge system and a temperature monitoring system. Further improvement can be anticipated with confidence on the basis of experiments and research currently in progress.

Thiokol-Longhorn, incidentally, is planning a program which will define optimum blade-to-bowl clearances in terms of both safety and mixer efficiency.

Vertical mixers, we have noted, gain an important safety advantage by eliminating submerged packing glands. At the same time, it must be admitted that some design features of this equipment pose new safety problems. Solutions to these problems may be theoretically feasible, but they do not exist in demonstrable reality.

The inherent characteristics of solid propellants may forever preclude our providing total safety from incidents. Be that as it may, I am confident that you find satisfaction with me in each forward step we take which decreases the probability of such incidents occurring.

Mr. Parrott: You mention the fact that you checked clearances between the blades and the blade and the wall on the Sigma blade mixers at frequent intervals. How do you propose to do this on the vertical mixer? What are your thoughts on that problem?

Mr. Martin: I regret very much that I can't give you a definite plan for checking clearances on the vertical mixer at this point. We have given it some thought and consideration, but we have not arrived at what we think is a logical conclusion. It is a tremendous problem and we recognize it as such.

Mr. Knasel: On your thermocouples, do you find that you have a temperature rise after you complete your cycle and how much on your thermocouple measurements?

Mr. Martin: I'll have to show you that on charts that I have with me. I do not have it readily available from memory.

Mr. G. R. King: Have you folks investigated the possibility of using commercially available mechanical seals with liquid purge systems?

Mr. Martin: Only a slight investigation of mechanical seals has been made, frankly, we are afraid of mechanical seals?

Mr. King: Because of the temperature?

Mr. Martin: Because of the friction at your point of sealing.

Mr. King: The liquid sealer could act as a coolant too possibly.

Mr. Martin: Possibly so, I hate to depend on the purge medium as a coolant, as a good lubricant, it isn't the perfect lubricant that you would like to have.

Mr. Bishoff: On the vertical mixer, have you decided on the separating distance between the bowl and the upper structure to provide the vent area.

Mr. Martin: No sir, we haven't. The mixer that we have is an existing mixer and we will be restricted in the amount of length that we can add to the sleeve. It presents a major problem and a major cost item to increase it. We feel that for this particular item, we will have to provide as much vent area as we can and let it go at that. We have considered vent area or the total amount of this vent area relative to a new mixer that would be bought that this design could be incorporated in the initial fabrication. We had hoped to be able to provide the vent area equivalent to 100% of the area of the mixing bowl diameter.

Mr. Bishoff: Would you please resubmit this when you reach that determination.

Mr. Martin: Yes.

Mr. McBride: Did you say that you were worried about the structural rigidity of the bowl around the flange which would affect the blade clearance with the bowl?

Mr. Martin: Yes.

Mr. McBride: And you are making changes, are these changes being integrated by Baker-Perkins or by Longhorn?

Mr. Martin: We're not to that stage at this time. I can only say at this point that we hope to be able to place this in the hands of Baker-Perkins.

RECOVERY OF MOTOR CASES
FROM
REJECT OR OVER-AGE SOLID PROPELLANT ROCKET MOTORS

by
H. L. Padgett
Longhorn Division
Thiokol Chemical Corporation

During recent years the problem of storing rejected and over-age solid propellant rocket motors has become increasingly acute. The problem arose because there are potential hazards in removing propellant from motors by mechanical means, because there are prohibitive costs and time losses in removing propellant from motors by chemical means, and because nobody wants to throw a motor away when the case alone represents an investment of up to $15,000 in a propulsion system such as the Pershing.

Be that as it may, you cannot store all reject and over-age motors indefinitely.

Consequently, further investigation into methods of removing propellant safely was essential. At Thiokol-Longhorn, the methods which are used, and which I will mention here, are drill-out, soak-out and burn-out.

There is an additional method, an operation involving the use of high pressure water jets, use of which was pioneered at Thiokol's Huntsville Plant as early as 1954. Subsequently, the technique was developed jointly by the Huntsville Plant and Thiokol's Wasatch Division into a full-scale practical method. This method will be discussed on the basis of information obtained from a report written by Mrs. Mary H. Larimer, Chemical Engineer at Thiokol's Huntsville Plant. I am not directly familiar with the method and I respectfully request that any questions which you may have concerning it be directed by W. F. Haite, manager of our Huntsville Plant's Propellant and Process Development Department. Mr. Haite is present at this seminar.

Drill-Out Method. Drilling and machining was one of the first methods used to remove solid propellant from motor cases. The techniques employed were essentially carry-overs from reclamation operations with high explosive projectiles. The method proved to have practical applications, particularly with smaller motors such as the Falcon and Honest John spin motor, but was gradually discontinued as improved techniques were developed. It should be noted that the older method, in addition to being comparatively unsafe and costly, left a layer of propellant on the case which still had to be removed by some chemical soak-out method.

Solvent Soak-Out Method. While reclamation of cases by solvent soak-out is feasible technically with reference to any size motor, the method generally is limited to smaller motors with thin webs--say two inches as a maximum thickness. This limitation reflects the high cost of solvents which are employed and the fact that chemical decomposition of thick webs requires an extended period of time.

Two solvent soak-out methods have been used at Thiokol-Longhorn. In the first method, usually called the vat process, the entire motor is immersed in a solvent-filled container. In the second method, called the circulating process, solvent lines are connected to each end of the motor case and solvent is pumped into the case interior. The vat process is preferred for small motors because of its simplicity. No complicated equipment is involved. By contrast, the circulating process requires relatively complex equipment including pumps, piping, a settling tank (for accumulation of solid particles before solvent recirculation) and a filter to remove fine particles which are not separated from the solvent in the settling tank.

Different soak-out solvents are required for different polymers used in fuel binder systems. For polysulfide polymers, methylene chloride based solvent has been developed by several manufacturers (Turco, Texo, Pennsalt). The exact composition of these solvents is proprietary information but it is known that they contain xylol mercaptan to break the polymer bond plus detergents to carry the particles out of the motor. They also have some kind of inhibitor which prevents the solvent from reacting chemically with the aluminum contained in many of the newer propellants.

Experience at Thiokol-Longhorn indicates that about 0.2 gallon of solvent is required to remove one pound of propellant. Removal rates vary from 20 pounds per day to 200 pounds per day depending on the type of propellant being removed.

As solvent costs about $2 per gallon, it can be seen that soak-out of large motors is very expensive in terms of material alone. This fact coupled with the long soak times, and attendant high labor costs, dictated the discontinuance at Thiokol-Longhorn of the soak-out technique for large motors.

Water-Cooled Burn-Out Method. At Thiokol-Longhorn, application of this basic technique has been applied to small and medium sized motors (e.g., the M58, XM-10 and XM-30). The technique probably would be applicable to large motors also. Undoubtedly it will be tried when investment required for facilities can be amortized by savings realized in reclaiming cases and metal parts.

Two basic methods of motor case reclamation using water cooling have been used at Thiokol-Longhorn.

For the M58 motor, the flight adapter is removed and is replaced by a thin walled burn-out sleeve. This sleeve protects the beveled seating surfaces on the nozzle end of the motor case and allows the motor to be submerged completely. (Sleeve design required a major effort before the item was capable of preventing burning of the beveled seating surfaces.) In this system, sixteen M58 motors are burned-out simultaneously by insertion in modified restrained drums filled with water. The motors are ignited by a system of safety fusing and black powder. To date hundreds of these units have been reclaimed with no malfunctions.

The second water-cool method involves the use of a spray. This method has the advantages of using more conventional static testing equipment than the submerged method does and of providing a capability to direct the cooling water spray at critical points on the motor case. This system is superior in cooling capacity because water circulates on the surface to be cooled in contrast to the static condition of the underwater set-up. Using the spray method, metal parts have been reclaimed from about 100 each reject XM-30 and XM-10 motors.

Advantages of the spray system include inexpensive, expeditious removal of propellant and minimal investment for equipment and facilities. Disadvantages include the uncertainty of results when defective grains are fired and the total loss of propellant which can be reclaimed (technically) for incorporation into a new propellant mix.

In both the underwater and spray cooling systems, units must be restrained effectively against accidental flight. For the underwater system, a substantial frame is used and the motors are inserted vertically for firing upward. For the spray burn-out method, motors are restrained essentially the same as in normal static firing.

The burn-out is accomplished remotely in both cases. For the spray method, the pyrogen opening of the unit is closed, and reject igniters of various types are used for igniting the grain. Operators are stationed in the control rooms of the static firing buildings and are protected in the same manner as during normal static firings. For the submerged system, long fuses are ignited and operators retire to a remote position during actual burn-out.

With the advent of very highly heat-treated motor cases and newer propellant systems, the burn-out process tends to become more critical. Specifically, case temperatures for Pershing motors cannot exceed 300°F (nominal) without some loss of physical properties occurring. This dictates that every possible precaution be taken to prevent this temperature being exceeded. For example, with certain grain voids and/or separations, repair work would be indicated to prevent excessive flame contact with the motor case. Further, by using the water spray

method, streams of coolant may be directed to specific areas in order to provide greater cooling than would be available ordinarily. It should be noted that this flexibility is not available with the underwater system. Specific rates of cooling, i.e., BTU's removed per unit of time, have not been determined. The highest case temperatures experienced were slightly over 200°F on reject XM-10 rocket motors.

For each type of motor to be burned-out, an adapter normally is designed to protect the aft surfaces of the motor cases. On the XM-10 and M58, these adapters mate to threads on the motor case itself. On the XM-30, the adapter mates to the normal bolted-on adapter connecting arrangement. No specific attempt has been made to provide nozzling to prevent chuffing. The adapters are inexpensive and can be used repeatedly.

Hydraulic Method. The application of high-pressure liquid jets for cutting is not new in industry. It has become important in hydraulic mining, de-coking, de-scaling, and cleaning metal parts. New uses of the technique are being developed as rapidly as production of more improved high-pressure equipment permits.

In 1954, a study was conducted at Thiokol's Huntsville Plant (then called the Redstone Division) to determine the feasibility of removing propellant from rocket motor cases with high-pressure water jets. Water was discharged from nozzles 1/16" in diameter at a rate of 13 gallons per minute and at pressures ranging from 3500 to 5000 pounds per square inch. The cutting rate was extremely slow and it was decided that this method of propellant removal would not be economical in terms of the equipment then available.

In 1960 an attempt was made at Thiokol-Longhorn to reclaim a motor case using high-pressure water jets. The equipment for this test included a leased truck-mounted pumping unit, a hand lance made of ½" pipe six feet long, and various types of nozzles. Water was discharged at a rate of 100 gpm and at pressures up to 4000 psi. With the single jet of water, only minor erosion of the propellant occurred.

An investigation of hydraulic removal of propellant was initiated at Thiokol's Wasatch Division in the early part of 1960. The high-pressure techniques and equipment employed in the mining and oil fields were studied and adapted or used in the rocket industry. Tests were performed with a truck-mounted pumping unit to determine the effectiveness of this method by removing inert propellant from a first-stage Minuteman motor. The results were very successful. Although the equipment was jury-rigged and the operation was comparatively inefficient, propellant removal at an average rate of 600 pounds/hour was attained. Water was discharged through two nozzles, each having a throat diameter of ¼", at pressures ranging from 1000 to 4000 psi. The discharge rate was 300 gpm at 3000 psi. An effective cutting depth of 8" was obtained under these conditions.

To deepen the cut made by water jets and increase the cutting rate, nozzle optimization tests were contracted for by Thiokol's Wasatch Div. Attempts were made to determine the effect of numerous variables, including nozzle diameter, water pressure, distance from nozzle to point of impact, temperature of water, temperature of propellant, nozzle shape, number of nozzles, and traverse speed of jet across cutting area. The capacity of available pumps was not high enough, however, to thoroughly investigate all variables. Samples of inert H-series, live H-series, and inert E-series propellant were cut during the experiments. The pressure ranged from 2000 to 5000 psi and the water discharge rate varied from 20 to 150 gpm. The nozzles were ¼" in length. The bore was straight from the entrance to the midpoint and tapered from the midpoint to the discharge end. The diameters ranged from 1/18 to 1/4".

Findings included the following:

1. Inert H-series propellant was more difficult to cut than either the live H-series or inert E-series propellant.

2. Greater cutting depth was obtained when the water was heated to 160°F. (This effect was particularly noticeable at pressures in the range of 5000 psi.)

3. Cooling propellant appeared to have an adverse effect on the penetration of the water jet. At a propellant temperature of -45°F, the cut was only ¼" deep at a discharge pressure of 3000 psi. No explanation for this phenomena was forthcoming; less resilient materials usually are easier to cut with high-pressure jets.

4. The rate at which the jet was moved across the propellant sample had an important effect on the depth of cut. A slower traverse speed produced a deeper cut; the greatest depth (5") was obtained when the jet remained at the same point of impact for several minutes.

5. The distance from the nozzle to the propellant surface could be increased as the pressure was increased. However, this distance did not appear to affect the cutting depth to a great extent.

6. The depth was increased by making several passes in the same cut.

7. A nozzle which had a 1" throat and 3/16" diameter appeared to produce the best cut.

No effort was made to determine the best material for the nozzles because of the brevity of the test period. Steel nozzles were used and no erosion was evident at the conclusion of the tests.

Another series of tests was performed in Long Beach, California. Samples of propellant were cut; liner and Avcoat (a material which Thiokol-Wasatch uses on exterior surfaces of rocket motor cases) were removed from steel plates with high-pressure water jets. Pressures ranging from 3000 to 9000 psi and flow rates of 15 to 148 gpm were used. Various types of nozzles were tested with diameters ranging from 0.093 to 0.185". A cut 12" deep was made in the propellant when water was discharged at 5000 psi through a 0.185" nozzle placed 8" from the surface and traversing 15 in./min. It was decided that water should be discharged at 300 gpm to adequately supply four nozzles.

Special Problems

1. A test was conducted at Thiokol-Wasatch to check for possible case damage resulting from high-pressure water jets. Two diametrically opposed streams of water were directed through 1/8" nozzles at 5000 psi against stationary points of impact on the inside of a flight-weight Minuteman case for ten minutes. The distance from a nozzle tip to the point of impact was approximately an inch. Results: No adverse effects were noted; the inside diameter was measured before and after the high-pressure jets were applied to opposite walls of the case and there was no difference in the measurements.

2. The question of possible hydrogen embrittlement of the case material as a result of this operation was put to a leading authority on the subject. He considered no such danger to exist. Although high-pressure water is used in the operation, the case metal itself is not highly stressed as it is in hydrotesting, for example. Hydrogen embrittlement of metal does not normally occur unless the case material is highly stressed or unless the operation is conducted at highly elevated temperatures. The hydraulic propellant removal operation is conducted at temperatures below 200°F.

3. Precautions were taken during the operation to protect the case from damage. Unpainted surfaces were coated with Cosmoline before and after propellant cleanout to prevent corrosion. The greased case was removed immediately and placed in an oven for a number of hours to remove all moisture. If any liner remained, it was soaked out with solvent. After dimensional inspection and hydrotesting, the case was coated with a preservative and stored in a warehouse.

4. Although a rocket motor case can be cleaned as completely as desired with high-pressure water jets, there is a point where it is more economical to soak-out the residue with solvent. Many hours could have been spent removing final traces of liner and insulation with high-pressure water. Some of the cases were removed from the pit before they were completely clean and soaked with solvent because of this apparent economic advantage. This optimum point should be determined definitely and exploited in a routine operation of this nature.

5. The propellant in the case head end presented several problems because of its dome shape. Special nozzle arms were fabricated for this section. (Attempts were made to use a long arm, 60° nozzle arrangement and eliminate an extra nozzle change.) Occasionally, several hundred pounds of propellant came loose from the head end in one mass and fell on the nozzle arms. The arms then had to be removed and different arrangements tried to cut up the propellant mass so that it would come loose from the water inlet line, which is encircled, and fall through the aft end opening. It was attempted to slice up most of the propellant during the first few passes, using a different nozzle arrangement to avoid having large sections fall on the nozzle arms later.

6. The problem arose as to the best position for mounting motors to bekprocessed. The greatest advantage of the vertical position is that the propellant and water fall freely from the motor. Disadvantages include difficulty in changing nozzles, the risk of personnel falling whenever adjustments have to be made in the nozzle rotating and traversing assembly, and the inability to observe cutting progress. These disadvantages are overcome when the motor is placed in a horizontal position; however, much of the water and propellant then remains inside the case and interferes with the cutting action of the jets. One solution to this problem is the compromise which Thiokol-Wasatch has proposed for their planned facility. There the motor will be mounted aft end low in a stand with the longitudinal axis of the case at an angle of approximately 30° to the horizontal.

In concluding, I would like to point out several additional facts about water jet systems.

With hydraulic removal of propellant, slivers and liner, also, are removed. Occasionally, a minimum amount of solvent cleaning is necessary to remove scraps of liner. There is no danger of fire resulting from impingement of the water jets on the propellant. With a propellant removal rate of approximately 800 pounds per hour, the operation requires a relatively short time. The equipment is not complex and, with the exception of the high-pressure pumps, is not expensive. The cost of the facility is soon repaid by the amount saved on the reclaimed cases, and the operation becomes quite profitable. Another important advantage of this method is that it can be used to reclaim the case in every type of rejected motor, including those with critically located voids and separations.

Because of the time limitation, I have hit only the high points of the four methods for reclaiming motor cases. I will be happy to answer questions on the first three methods discussed and, as previously mentioned, Mr. Bill Haite of Thiokol's Huntsville Plant at Redstone Arsenal is present and will answer questions on the hydraulic method of propellant removal.

RANGER 3 SAFETY CONSIDERATIONS

by
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Ranger 3, launched early this year, was the first attempt by the United States to take close-up pictures of the moon and to make measurements on the lunar surface. Seven hundred and twenty seven pounds of machinery was called on in a sixty-six hour flight to the moon to perform the most complicated series of events a U. S. Spacecraft has yet been asked to undertake. It was asked (1) to leave the earth, achieve a parking orbit, reach escape velocity of 24,500 miles an hour; (2) perform a three-axis maneuver in space to lock onto the sun and earth; (3) accept correction commands from the earth, change its orientation in flight, and fire a mid-course motor to put itself on a collision course to the moon; (4) re-establish its lock on the sun and earth; (5) perform a terminal maneuver when it gets to within 5,000 miles of the moon; (6) take television pictures of the lunar surface as it approaches the moon; (7) make studies of the composition of the lunar surface in its radar reflection characteristics; (8) separate a retro rocket and capsule system from the spacecraft when it was 70,000 feet above the lunar surface; (9) fire a retro rocket to slow the capsule down from 6,000 miles an hour to zero velocity 1100 feet above the surface of the moon and (10) detach an instrumented capsule containing a seismometer from the retro rocket so that it rough-landed after a free fall from 1100 feet, surviving the landing, positioning itself and then send for thirty days information on earthquakes and meteoric impacts.

The Ranger system (Figure 1) utilizes an Atlas booster and sustainer for the first stage, an Agena B as the second stage, and the Ranger spacecraft. The spacecraft (Figure 2), about five feet in diameter and fifteen feet long in the folded position, is initially confined within the shroud for environmental protection. Following the first stage sustainer burnout, the shroud is ejected. At the conclusion of the first Agena burn, the spacecraft is in a coasting or parking orbit. A second ignition and burn of the Agena, concluding in spacecraft injection, precede the separation of the spacecraft from the Agena B.

After separation, the spacecraft goes into an acquisition operation. The solar panels are erected (Figure 3) and the high-gain antenna is rotated to a preset hinge angle (Figure 4). The attitude control system is activated and the solar sensors point the roll axis of the spacecraft toward the Sun thus placing the solar power system in operation. The spacecraft then turns about the roll axis until the antenna beam points

toward the Earth. Upon Earth acquisition by optical sensors which move with the antenna, the high-gain communication link is established. The spacecraft then continues to coast with its roll axis pointed toward the Sun and its high-gain antenna pointed toward the Earth.

After a suitable tracking period, the required trajectory corrections are computed and the corrective maneuver commands are transmitted to the spacecraft. The resulting midcourse maneuver will turn the spacecraft to the prescribed angle in space, will effect a correction in the trajectory by an application of thrust, and will then return it to its Sun and Earth orientation as before. The gamma ray boom is extended after this midcourse maneuver (Figure 5).

As the spacecraft approaches the lunar surface, a terminal maneuver is performed to align the vidicon camera for high-resolution pictures of the Moon, and to orient the lunar landing capsule for its subsequent separation and retrorocket controlled descent, to deploy the omnii-antenna and the radio altimeter (Figure 6). Commands from the Earth initiate the terminal maneuver. At a signal from the radio altimeter, the capsule spin rocket motors activate and separate the capsule from the spacecraft (Figure 7). The spacecraft will plunge separately into the lunar surface and be destroyed by the impact. The retrorocket (Figure 8) will slow the capsule descent rate. The capsule timer will initiate the separation squibs upon retrorocket burnout, allowing the capsule survival sphere to fall free to the Moon's surface.

As can be seen from the foregoing descriptions, the Ranger 3 spacecraft is a rather complicated piece of machinery. It is also an interesting problem from the safety standpoint for several reasons:

1. Potential energy is aboard in the form of electrical batteries, high pressure gas, solid propellants, liquid propellants and compressed springs, and in most cases there is more than one variety of each of these types of energy.

2. These various forms of energy are designed to be released by the operation of a variety of electrically operated devices including electronic timers, explosive valves, thermal switches, squib switches, pyrotechnique igniters, pin pullers, bolt cutters, etc. As some of these devices operate on low currents, there is a constant potential hazard due to electromagnetic radiation from any source and from accumulated static charges.

3. A toxic hazard exists due to the liquid propellants and to the sterilizing agents.

4. Although all of the foregoing hazards are commonplace in the missile business, some new aspects to the problem are present -- because the Ranger 3 is completely assembled, fueled, pressurized, shrouded, and sterilized prior to transportation to the launching pad

for assembly to the Atlas-Agena, only external electrical and mechanical connections are completed on the pad.

The greatest hazards to personnel are probably associated with possible high rates of energy release. In probable order of magnitude, these are:

1. The retromotor, containing approximately 180 lbs. of solid propellant and rated at 5,000 lbs. thrust for 10 seconds duration.

2. The high pressure gas storage bottles. The attitude control system utilizes three 83 cu. in. titanium bottles charged with nitrogen to 3710 psi at 80°F. These bottles have a safety factor of 1.67 to actual proof pressure and 2.46 to minimum burst pressure, based on test samples. These safety margins are considered adequate provided no physical damage is experienced, such as might be caused by a dropped wrench. One additional bottle of similar size and design is helium pressurized to 3000 psi for use with the mid-course motor liquid propulsion system. Although still a potential hazard, the lower pressure level gives greater safety margin.

3. The mid course propulsion system (Figure 21) consists essentially of a 50 lb. thrust mono-propellant hydrazine motor, a prepressurized fuel tank containing less than 15 lbs. of hydrazine, a small nitrogen pressurized system containing a few cubic centimeters of nitrogen tetroxide for combustion ignition, the high pressure helium reservoir previously discussed, plus associated valving and piping. Here again is the hazard of pressurized tanks, coupled with the presence of a high energy fuel and a small amount of toxic oxidizer.

4. The lunar capsule contains two squib-operated penetrators designed to vent the flotation fluid after lunar impact. These penetrators are comparable to .45 cal. bullets, hence represent some hazard to personnel in the immediate area.

5. The spin-motor assembly is a 2 sec. duration, three nozzled solid propellant motor containing less than 1 lb. of propellant.

6. Other devices, such as squib-switches and bolt cutters are of relatively low hazard in themselves, but their accidental operation could in some cases have catastrophic effects by initiating larger energy releases.

Since much of the operational safety is dependent upon the proper functioning of the electrical circuits, some discussion of this circuitry is warranted. Figure 10 is a greatly simplified diagram which shows the basic operation of the Ranger Central Control and Sequencer, Squib Firing Assembly, and Ground Service Equipment. Only one of the several squib firing circuits is shown.

The basic operation in flight is as follows:

1. The power switch is turned on prior to lift-off, starting the counter.

2. The inertia switch operates due to booster acceleration at approximately 100,000 feet and arms the squib firing relay.

3. A predetermined number of counts actuate the electronic relay which in turn actuate the power relay.

4. Current flows from the power relay through the closed contacts of the cut-off relay to operate the squib firing relay.

5. The squib firing relay sends current to the squib and also, via the cut-off timer, opens the shut-off relay, thus releasing the spring-return squib firing relay to conserve battery power in case of a shorted squib.

Obviously these functions could be accomplished with considerably less hardware than is shown. The extra equipment is included for test and safety reasons, as follows:

1. The "inhibit" feature, shown in block diagram only, prevents the accumulation of pulses by the electronic relay network. The "inhibit" is kept on until shortly before lift-off.

2. The "clamp" provides a short circuit across the power relay driver, thus preventing accidental operation due to an electronic relay malfunction. This "clamp" is removed by the sequence timer (counter) well after lift-off.

3. The power relay contacts are magnetically restrained in the position to which they were last operated.

4. The power relay is held open by ground power until shortly before lift-off, and an extra set of contacts actuate a relay position indicator light.

5. When the cut-off relay is reset, the correct position of both the cut-off relay and the squib firing relay is shown by an indicator light. In some cases the extra contacts of the squib firing relay are used to provide a ground station test circuit to verify that squib circuits are intact.

6. The inertia switch closes and latches mechanically when exposed to an axial acceleration of 5gs for one second. Timing is obtained by air damping.

7. The safe-arm relay is necessary to by-pass the inertia switch for ground test purposes. Upon completion of testing, correct positioning of both the inertia switch and the safe-arm switch is shown by an indicator light.

One of the final operations of the Central Control and Sequencer is to send the signal that starts the lunar radio altimeter. At a lunar altitude of 70,000 feet, a contact closes in the altimeter sending a signal which fires the bolt cutters to separate the lunar capsule from the 'bus' and provides the fuzing signal for the Power and Sequencing Assembly (Figure 11) in the lunar capsule.

The Power and Sequencing Assembly operates as follows:

1. When the 5g inertial switch is closed during boost, timer T1 starts.

2. If the inertia switch remains closed for one second, current is applied to arming squib switches SQ1 and SQ2, burning out shorting fuse F1 and operating the switches. These squibs have a maximum no-fire current rating of 0.07 amperes, hence the fuse is used to provide a short circuit to dissipate low stray currents.

A fuze is not used with squib switches 3 and 4 because:

(a) It is essential that these squib switches operate prior to the separation bolt cutters (rated at 0.5 amperes maximum no-fire current), because separation cuts the fuzing lead.

(b) The fuzing lead is shorted by an extra contact in the altimeter switch prior to altimeter switch actuation, hence no fuze is needed.

3. Operation of the fuzing squib switches starts timers T2, T3, and T4, which sequentially fire the spin motor, the retro motor, and the upper bolt cutters, separating the impact sphere.

Both the spin and retro igniters have no-fire current ratings of 0.2 amperes. The spin igniter is shorted by one ampere fuze, but a heavy shorting bar is provided for the more hazardous retro motor. This shorting bar is automatically removed when the lunar capsule is separated.

The upper bolt cutters are also fuze-shorted.

Due to weight and size limitations, the P. and S.A. presents two problems from the safety standpoint that are not present in the circuits discussed earlier:

1. The P. and S.A. is a 'one-shot' device, hence cannot be cycled and tested for proper operation.

2. After assembly of the lunar capsule only the two fuzing signal wires are accessible for test purposes, hence the fuzing squib switches are the only components whose condition can be verified externally.

Time will not permit a detailed discussion of the circuitry of the impact sphere. The only real hazards in this sealed structure are the two penetrators which are fired by a 15 minute timer which is started when an inertia switch has experienced 25 gs. for one second, which occurs during retro burning. Normal handling and even dropping the sphere will not trip this switch, hence it is reasonably safe. Again, however, the absence of any test connections results in cautious procedures. It is standard practice to wait 15 minutes after a spin-balance test before approaching the sphere, thus permitting the timer to run out if it has been started. In addition, a metal band is kept around the sphere at all possible times during handling operations.

Assembly and checkout of Ranger 3 began in the AE Hangar in the industrial area at the Atlantic Missile Range. This hangar is not in a hazardous area, hence no pyrotechniques, or propellants were present and no high pressure gases were used. A complete checkout of the spacecraft system was carried out at this location, using dummy parts and electrical simulators where necessary to checkout systems that would later include high energy devices.

It is interesting to note that the only personnel injury during the Ranger 3 operation at AMR occurred during this relatively non-hazardous phase. A technician 'blacked-out' and fell from a ladder while making an adjustment in the empty shroud while it was suspended from a crane hook. The shroud had been purged recently with dry nitrogen, but it is not clear whether lack of oxygen or momentary vertigo caused the fall. A shroud ventilation system was improvised and no further trouble was encountered.

Upon completion of the systems test, the spacecraft was moved to the so-called explosive safe area. This complex consisted of three main buildings:

1. The Propulsion Laboratory where the midcourse propulsion system was assembled, leak tested, fueled, and pressurized.

2. The Capsule Laboratory where the complete lunar capsule, including retro-motor, spin motor, and impact sphere was assembled, balanced, and checked out.

3. The Assembly-Sterilization Laboratory where the midcourse propulsion system and the lunar capsule were finally incorporated into

the spacecraft, all interface electrical connections were completed, the attitude control system was pressurized, the shroud installed and the final gas sterilization with ethylene oxide was performed.

Time will not allow a complete discussion of all the safety procedures used throughout this operation, and many were very routine and commonplace. Some of the conditions were rather unique, however, and will be discussed in some detail.

The midcourse propulsion system presents a few unusual problems in that it is filled with propellants, and completely pressurized, including pre-pressurization of the hydrazine tank and the nitrogen tetroxide starting cylinder, prior to installation in the spacecraft. Only one electrical plug remains to be connected after this installation. All midcourse fill procedures are accomplished manually except for pressurization. Because of the several days that lapse between pressurization and firing, a leak-tight unit is essential, hence pressures are monitored with small mechanical dial-type gages for several hours after pressurization and before installation into the spacecraft after this installation, which takes place in an air-conditioned room, periodic air samples are taken to detect any possible propellant leakage:

Most of the critical safety problems center around the lunar capsule, due primarily to potential high energy release rate of the retro-motor. It was felt that adequate personnel protection was probably impossible in the event of accidental ignition in the relatively small rooms involved. Hence field efforts were concentrated on:

1. Rigid adherence to written, step-by-step procedures which had been carefully worked out in advance.

2. Thorough education of all involved personnel concerned to the problems involved, signs of malfunction, and evaluation procedures.

3. Reduction of the number of exposed personnel to the minimum possible.

4. Facilitation of rapid evacuation via panic hardware, break-away plastic door coverings, clear passages, etc.

A series of large water spray nozzles surrounding the working areas could be activated via quick opening valves either inside or outside the building. During final electrical connections the doors were held open and an observer was stationed at the water control valve outside the building.

One of the unknowns that caused much concern and is still largely unanswered is the possibility of squib actuation by electromagnetic radiation or static electricity. Each squib has a lead wire which

forms some kind of an antenna, and, particularly at a place like Cape Canaveral, there is always some man-made radiation of some frequency present. In addition there are the hazards of electrical storms and static electricity.

Calculations were made for each squib, including the effect of lead length, twisting, shielding, shrouding, etc., to arrive at some idea of the magnitude of the hazard. On the basis of these intentionally conservative calculations, a survey of known radiations sources, and some field strength measurements, a rather detailed list of safety recommendations were developed. They can be roughly summarized as follows:

1. Avoid close exposure to certain known sources of radiation, particularly during transportation to the pad.

2. Keep the spacecraft grounded and shrouded whenever possible.

3. Evacuate the area if an electrical storm approaches within three miles of the pad or two miles of the hangar (Figure 12).

This is obviously an over-simplification of a problem which needs much more investigation.

Conclusion

The safety problems met and solved on the Ranger project are undoubtedly very minor compared to problems that will arise on future spacecraft. The keys to safe handling of these future operations will be, as they have been in the past:

1. Good design
2. Good workmanship
3. Well worked-out procedures
4. Most important of all, dedicated, well informed, safety conscious personnel.

Mr. Minnich: What is the maximum acceleration this system must withstand and what in your opinion is the weakest component in this respect?

Mr. Bell: During the boost, about 5 gs or a little more that the whole system withstands. During the retro-motor firing, it's 25 Gs or 30 or something, I'm not sure but it's above 25 gs and I don't know as I could say what the weakest link in this is. Probably it would again be relayed, I imagine, I'm only guessing. I'm sorry I can't say. Relays are a standard problem tho because they're a device that has to move when you want it to but when you don't want it to, it's tough to keep it there.

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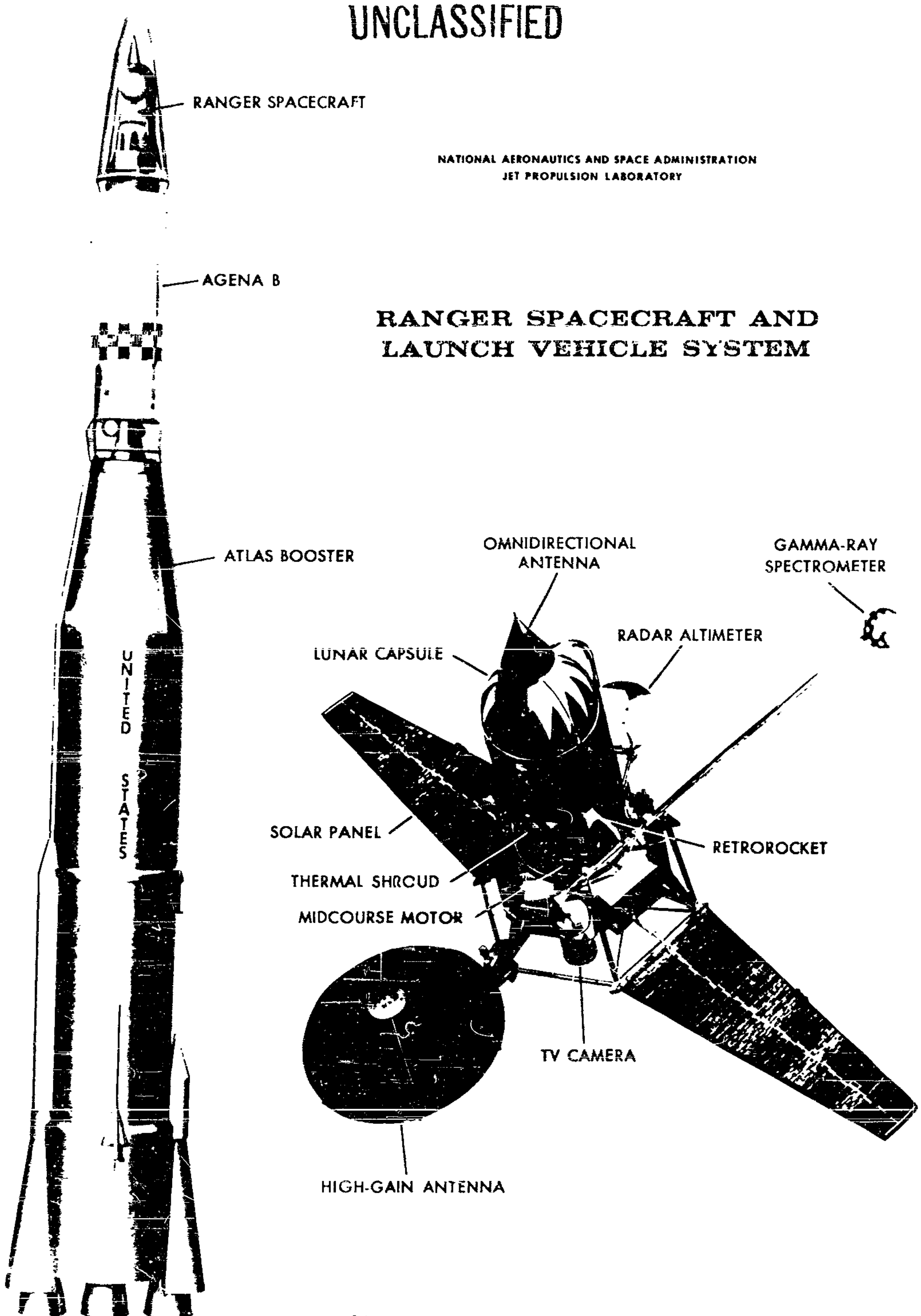

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Figure 1

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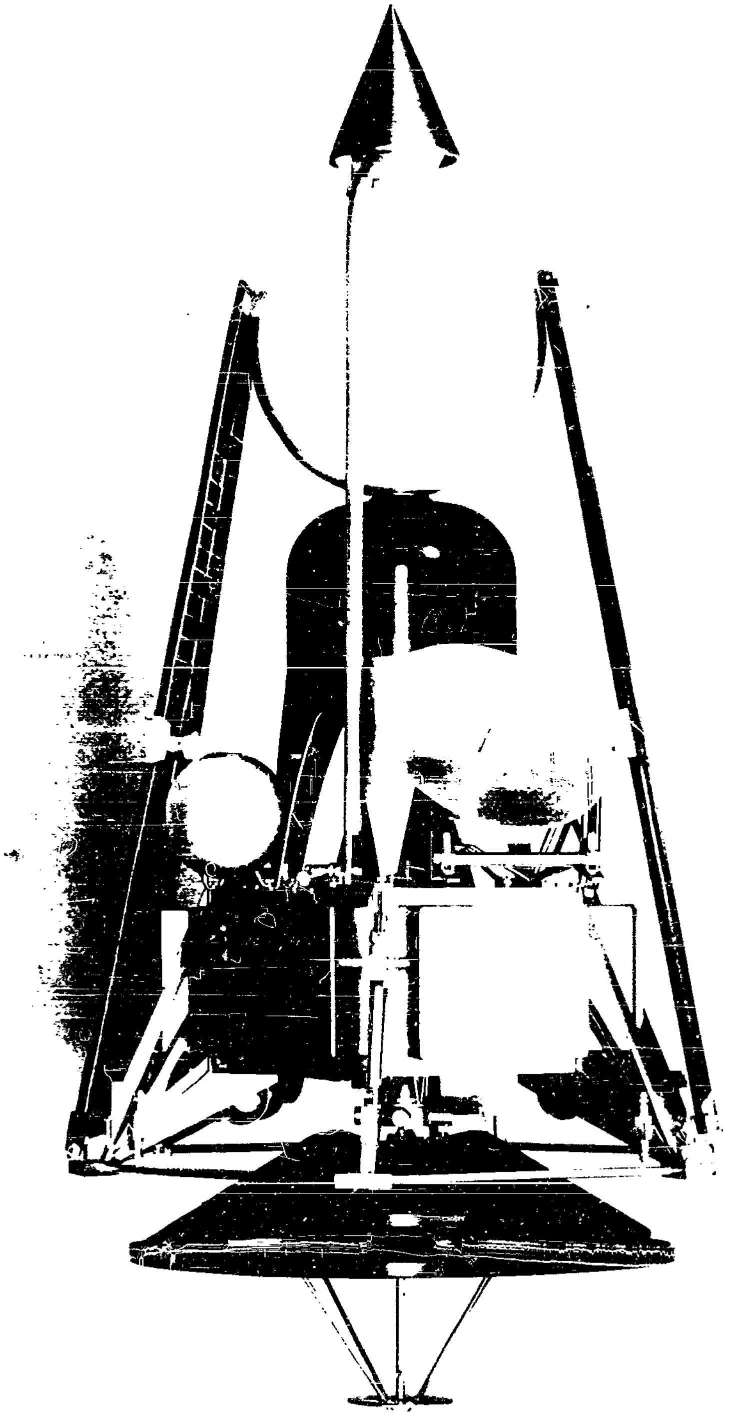

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Figure 2

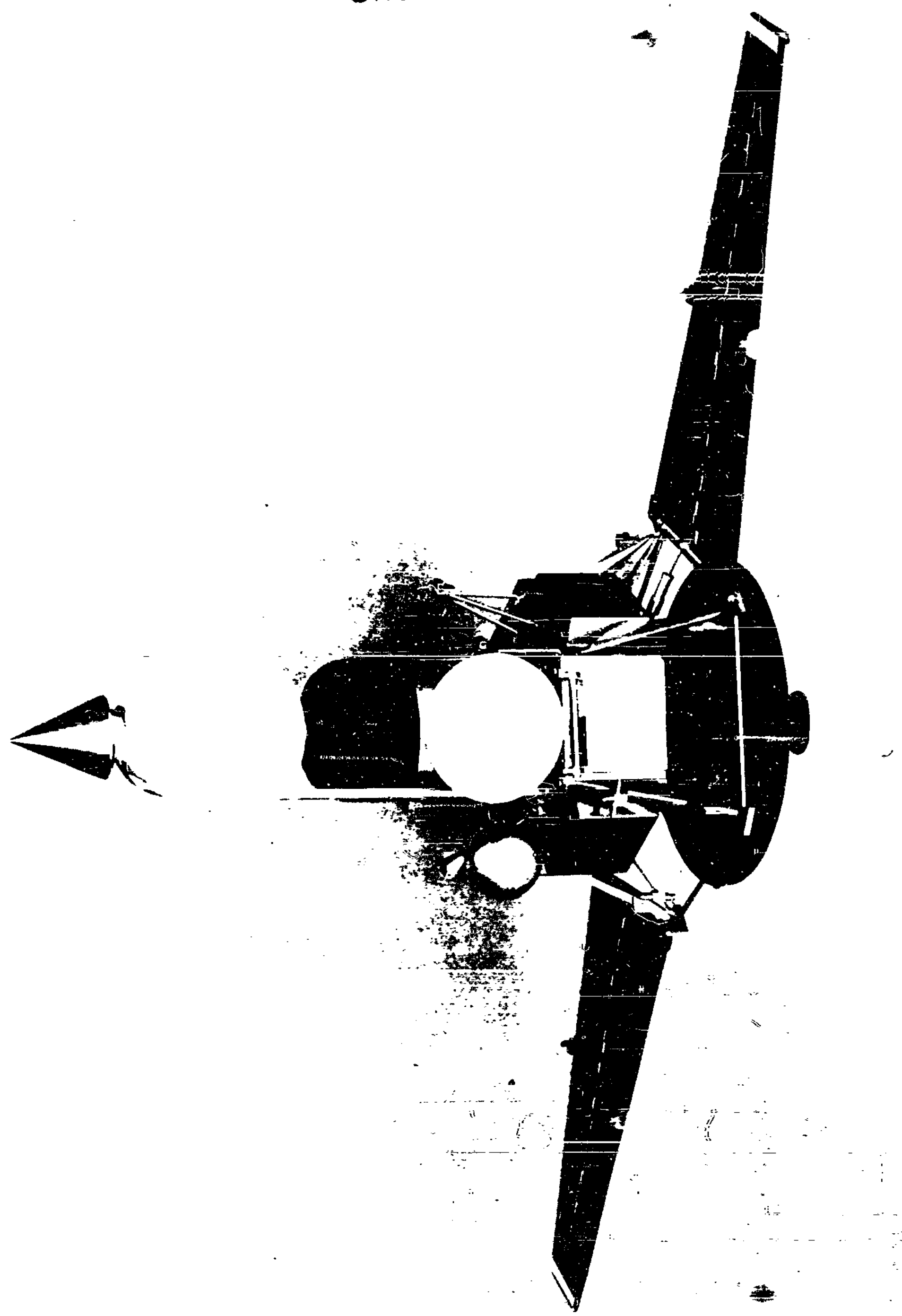
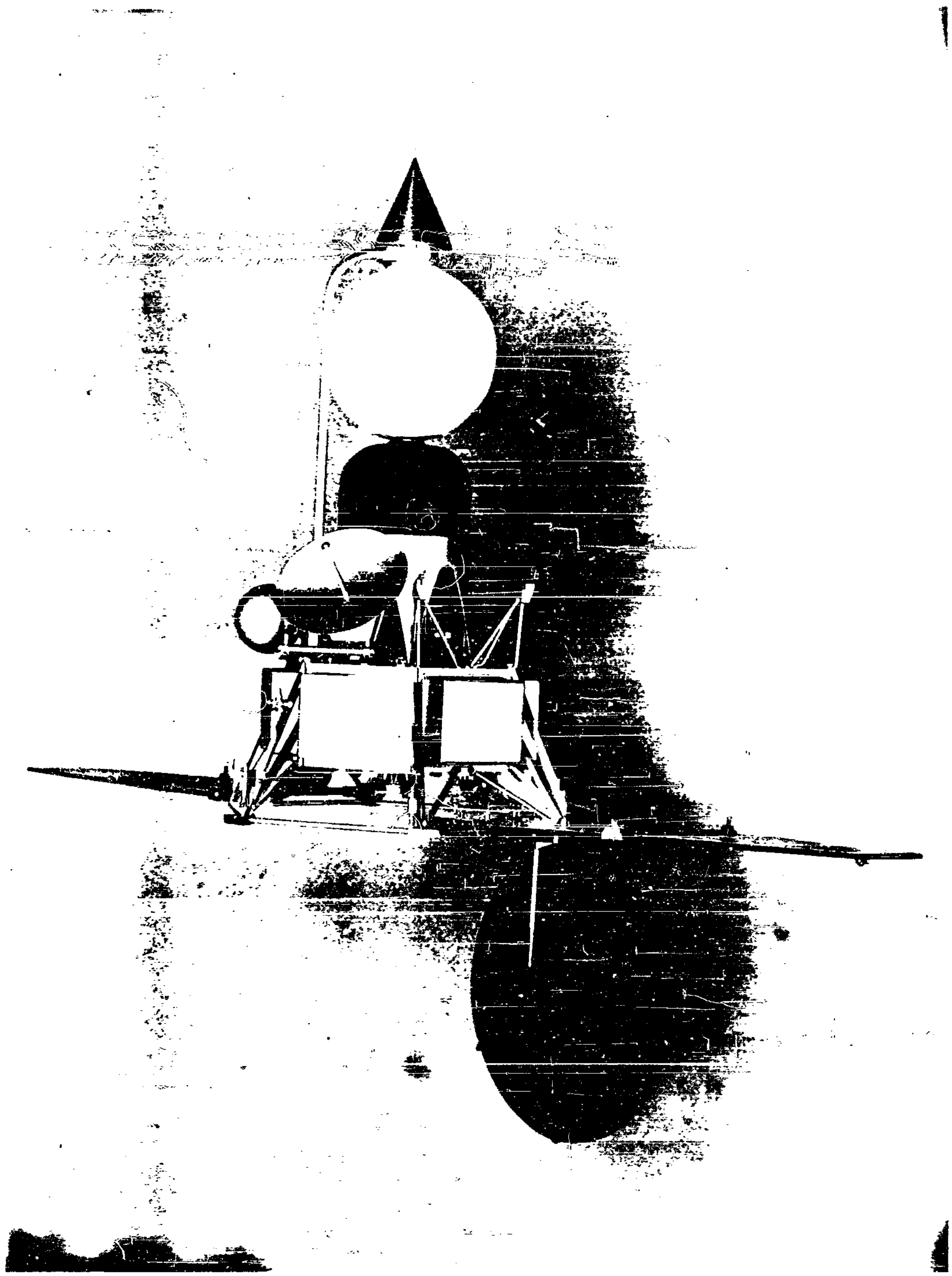


Figure 3

UNCLASSIFIED



UNCLASSIFIED

Figure 4

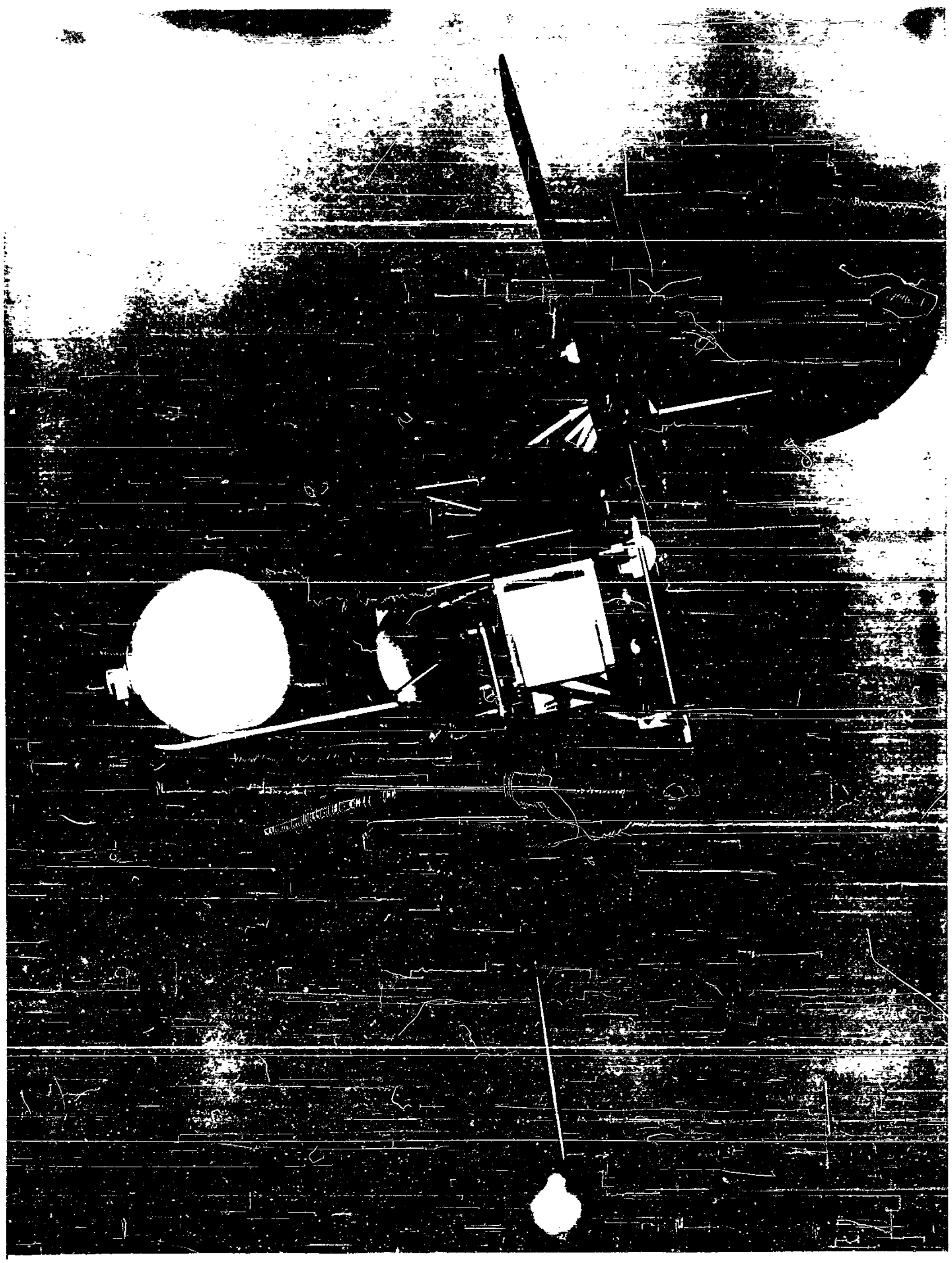


Figure 5

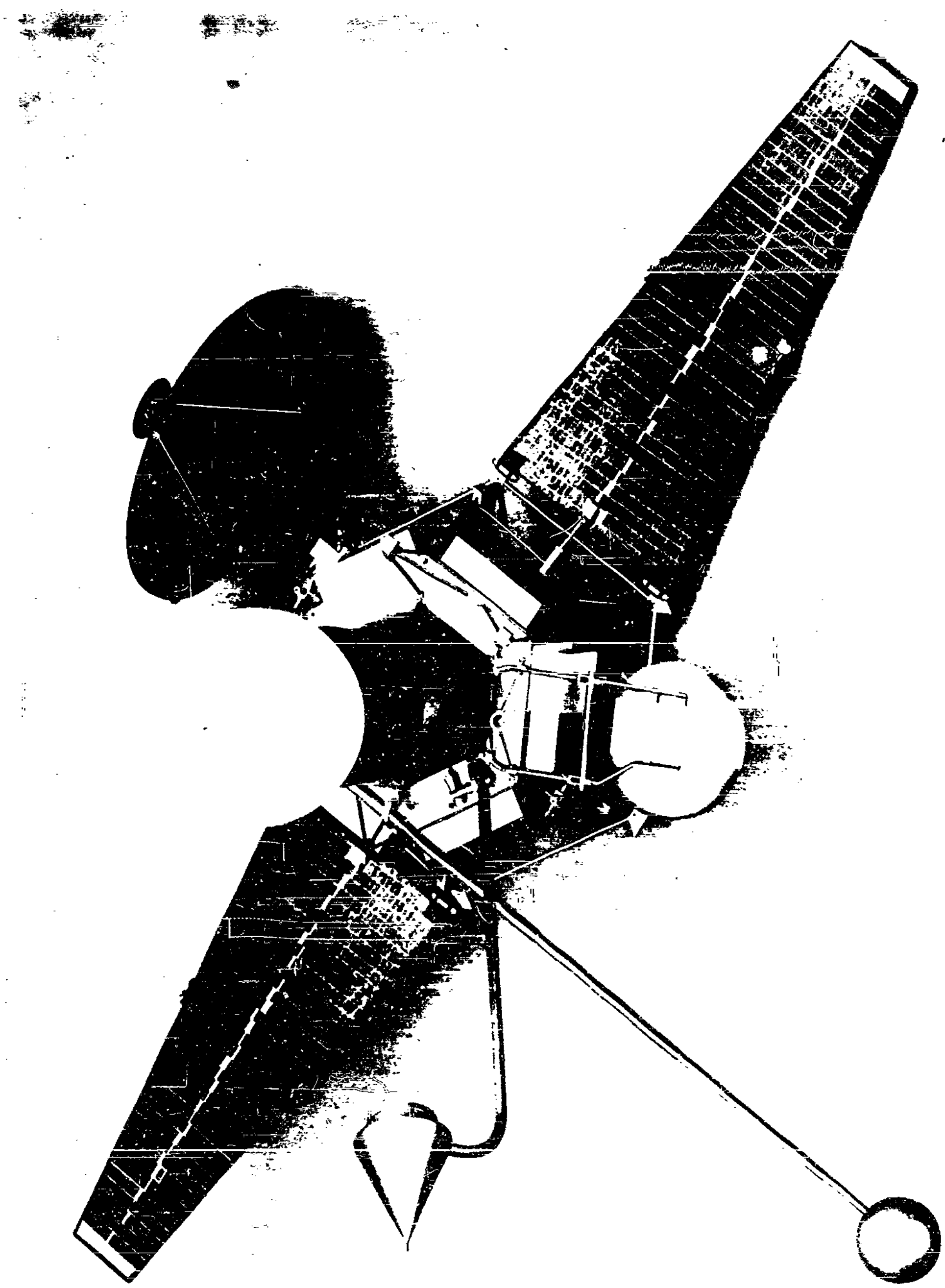


Figure 6

Figure 7

LUNAR CAPSULE
GENERAL CONFIGURATION NO. 2

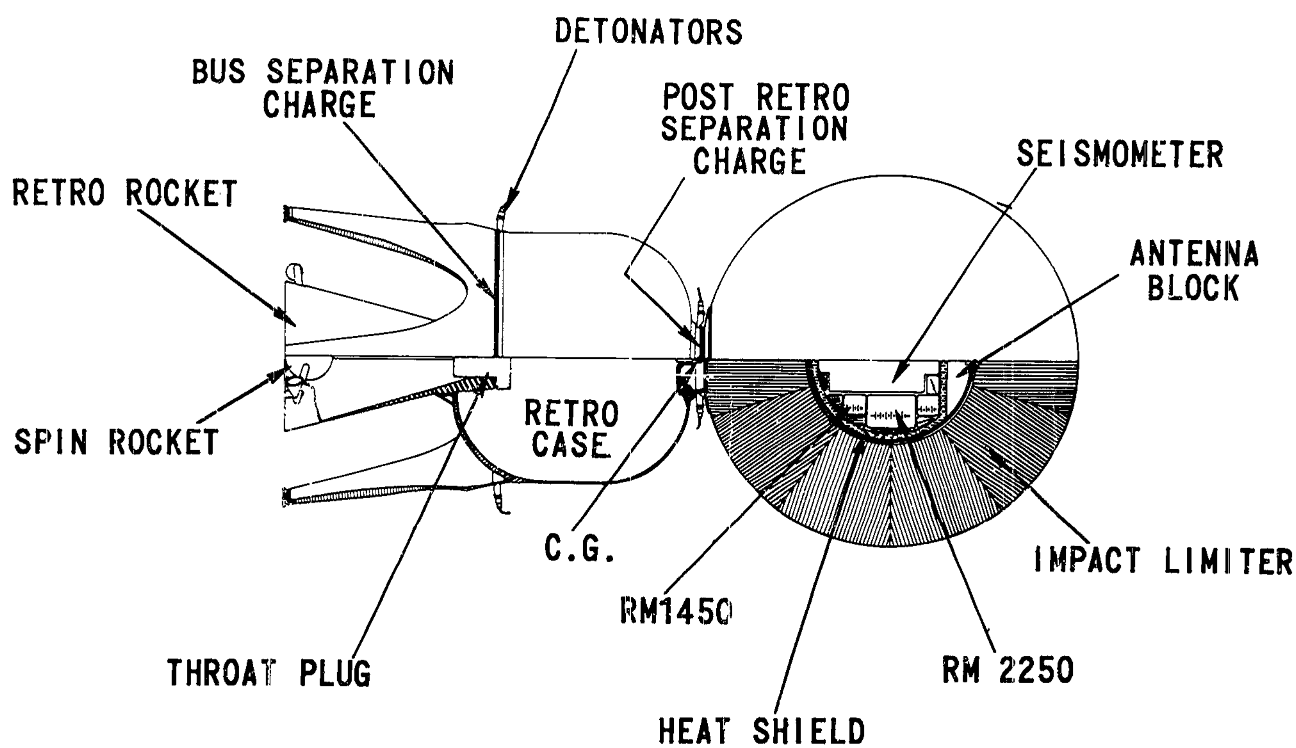


Figure 8

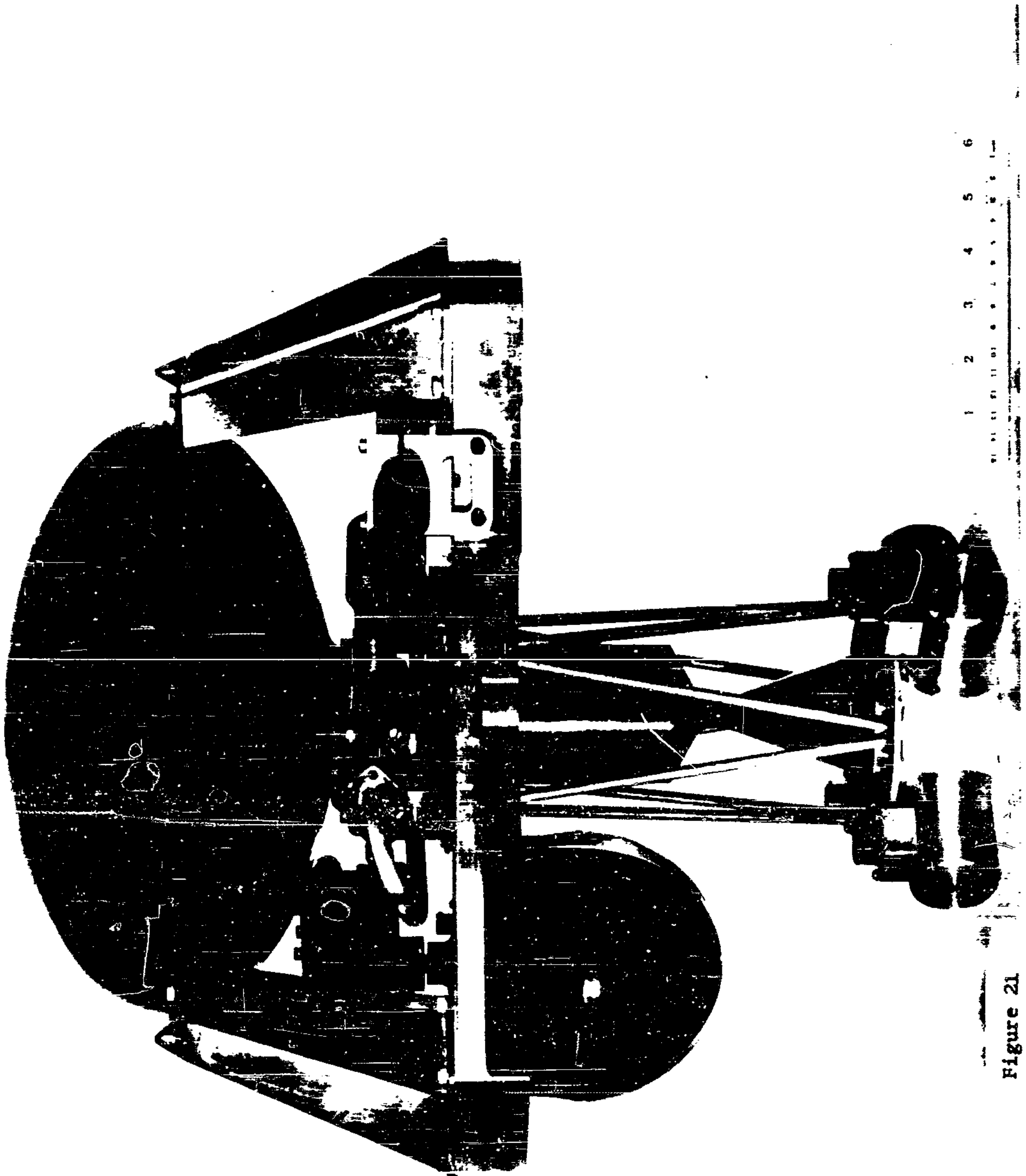
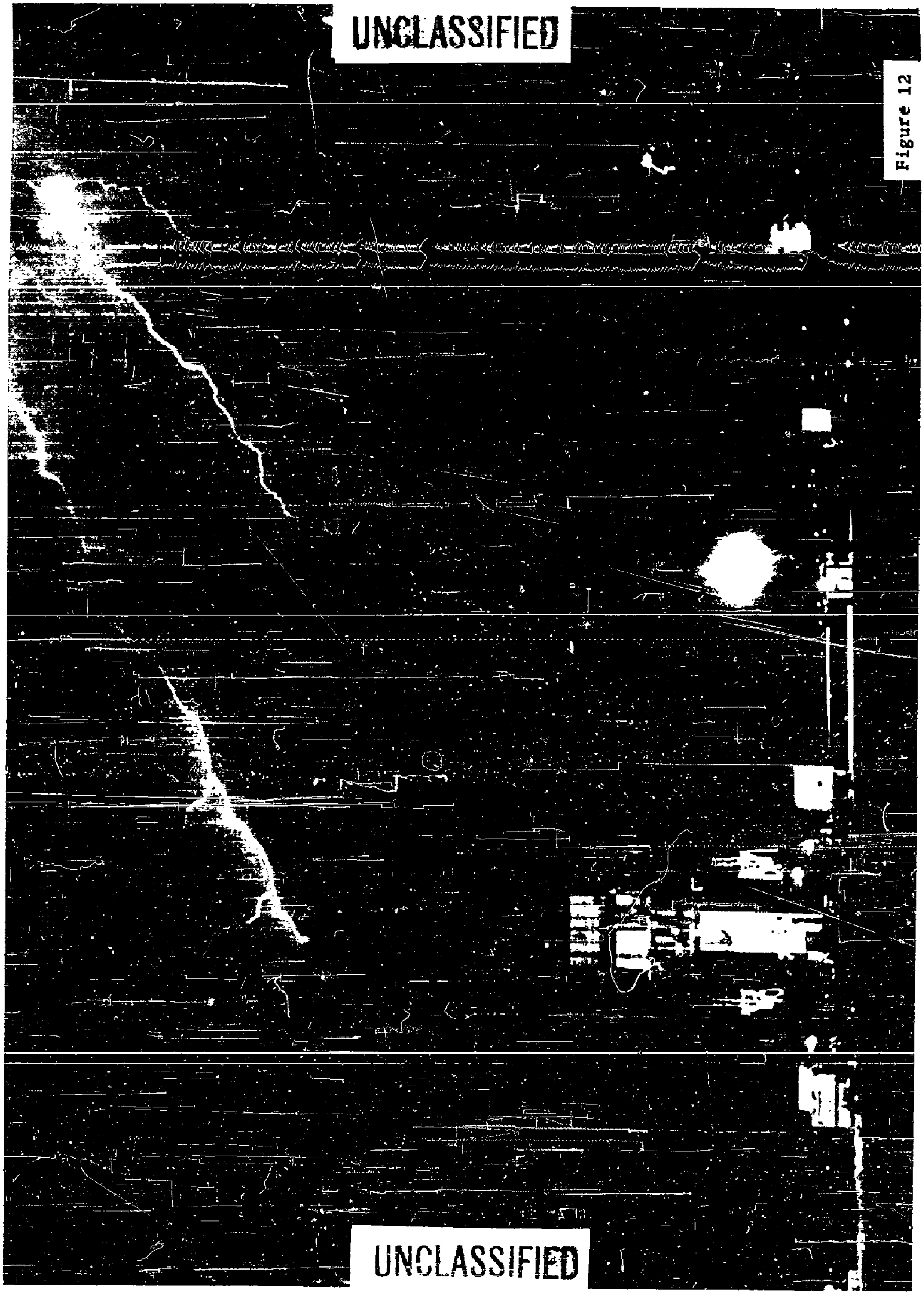
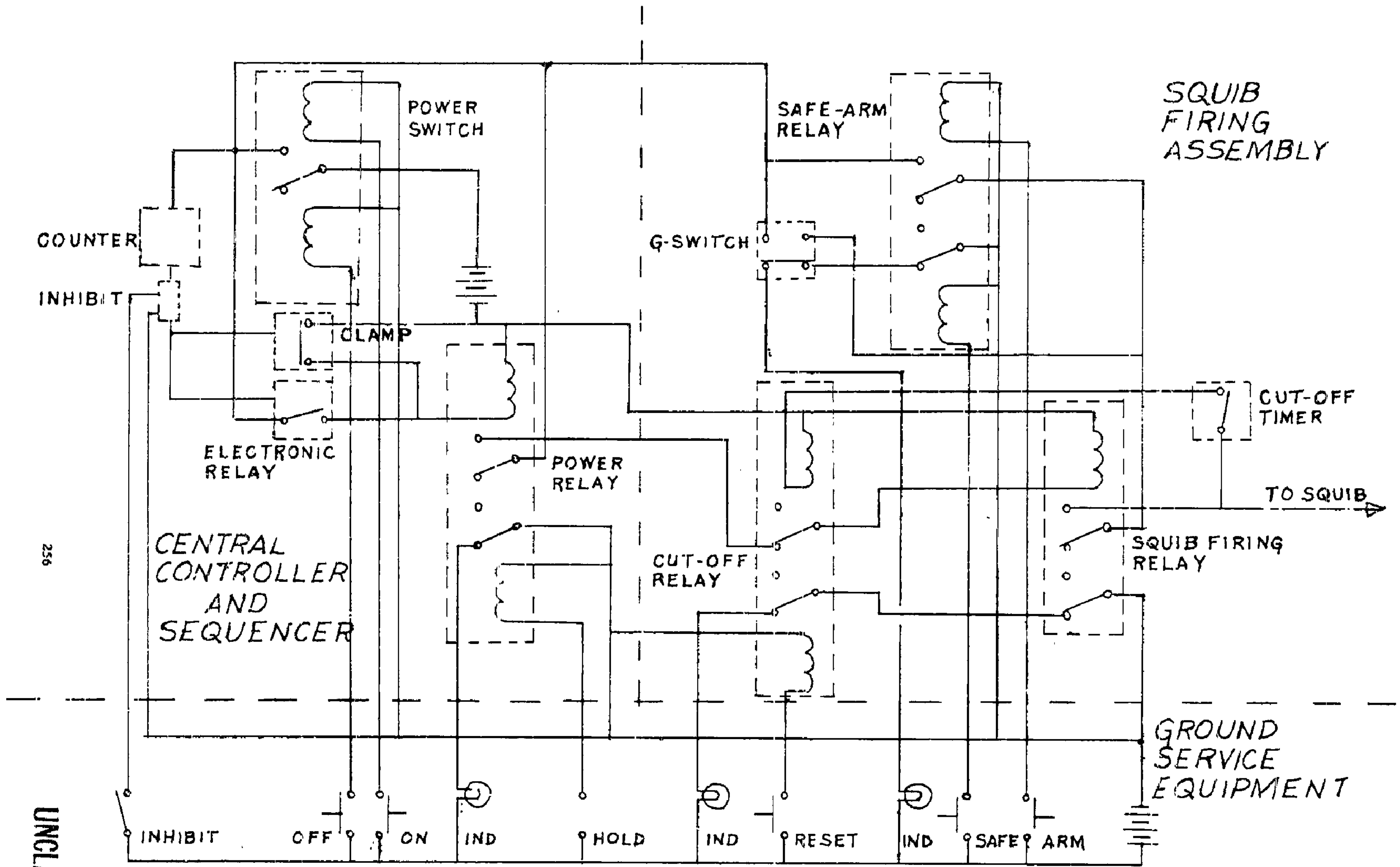


Figure 21

Figure 12

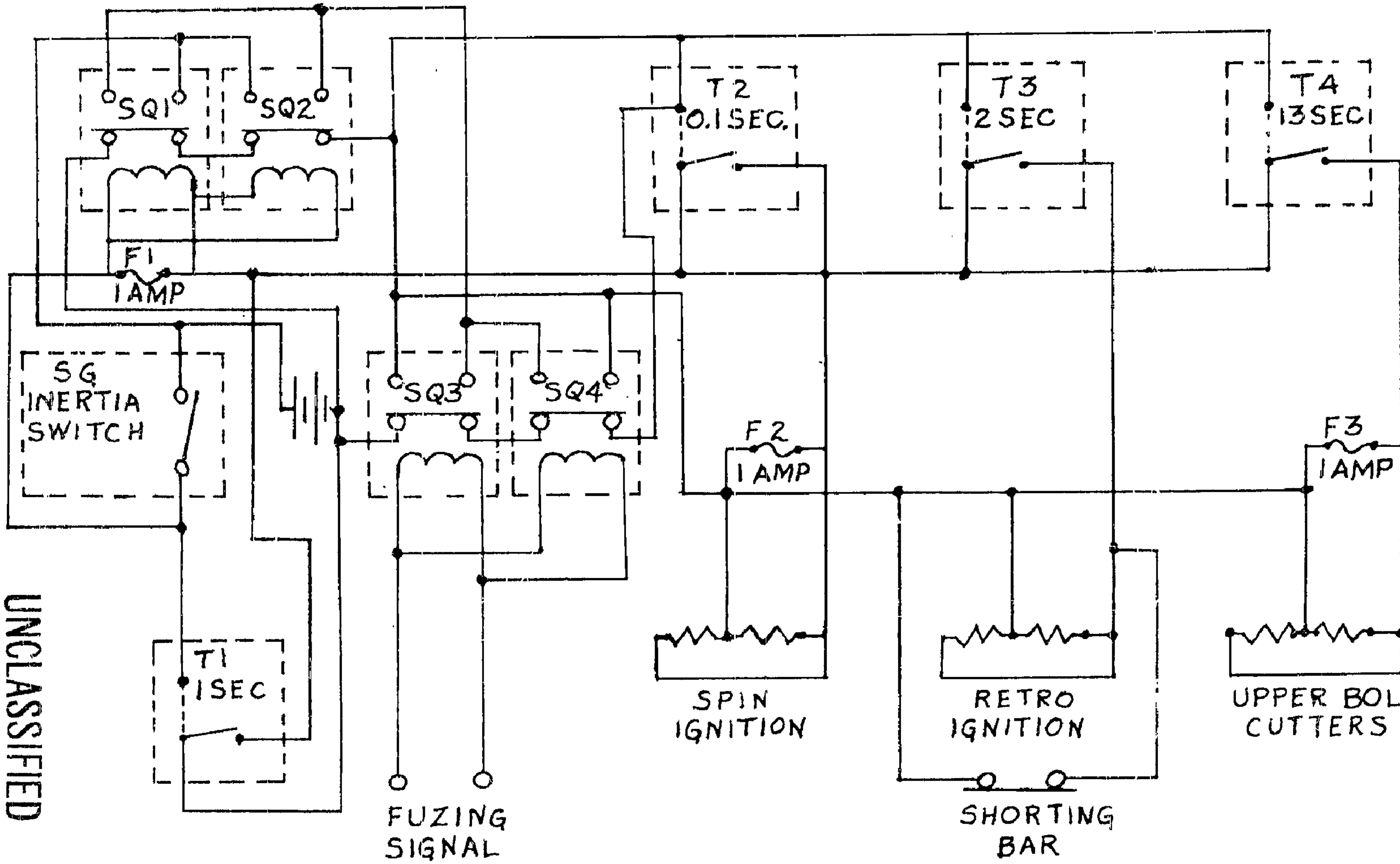




SQUIB FIRING CIRCUIT FUNCTIONS

FIG. 10

UNCLASSIFIED



POWER AND SEQUENCING ASSEMBLY

FIG. 11

UNCLASSIFIED

Mr. Paul King: Are all the circuits grounded to the skin of this thing or are they all two-wire aboveground circuits?

Mr. Bell: They're all two-wire circuits, they're not grounded to the skin as such. Perhaps they are back far enough, I'm not sure they're floating aboveground either, because grounding spacecraft frame is supposed to ground everything on it for working conditions. Somewhere back it does, but they are all two-wire circuits. I can't emphasize enough this problem of radiation. I was rather disappointed not to see papers here on the agenda on this field because I know a lot of people are concerned with it.

Dr. Johnson: We are intensely interested in this radiation problem for our tactical Navy missiles. (This is Confidential) We have a 2½ mega-watt radar transmitter on some of our bigger aircraft carriers and we have all kinds of things going off accidentally. It's an extremely serious problem, we're redesigning all the igniter circuits on all of our tactical missiles right now and Dahlgren is taking a leading part in this thing. They have a set-up down there for testing all these things for electromagnetic radiation hazards. This is Project HERO, you're probably familiar with it. I think it would be worthwhile for your people and our people to touch base on this thing. We've got a lot of good new design or concept for this thing.

Lt. Rubinstein: We've been extremely interested in the radiation problems, especially on our Scout and Beanstalk programs at Point Arguello and I would like to know if the paperwork is available on the study that was done at the Cape and I would also like to know what papers are available on this entire problem of radiation. There's been an awful lot of concern about it and I would like to see a central point of contact being made to where we could get as much information as is available on this subject.

Mr. Bell: Yes, I would too. Some of these working papers I'm sure we could arrange for you to get copies of. I don't know if any of them are in publication form, they're more in the working paper range. One more thing I might comment on, the type problem you hit. For instance, we know that you want to avoid close proximity to rapidly changing high current DC circuits such as arc welding machines and things of this nature. We were within a couple of days of being ready to go out to the pad at the Cape and a photographer approached me. He said "say, we're going out early in the morning, 2 o'clock, and we'll want film coverage of this - is there any problem with arc lights?" Who would have thought of arc lights. I said "these being machinery, let's see." It turns out there's something around 100 to 125 volts and 150 amps DC and buttering him along you know. I said "how many have you got?" He said "well, we had 35 last time, we hope to have more this time, there's a whole bank of them right alongside where you're dragging this vehicle by with the spacecraft aboard." So what did we do, we started

trying to find out and could find no information from anyone that had done any measuring. So we set up RF field intensity measuring gear which we had available but not completely. We moved in on these things to focus 5 ft. completely around them, swept the frequency from 0 KC to 15 KC and then we had 150 KC and then on up to something like 5 megacycles. Everything we had available and we found not a trace of energy anyplace, not a thing - nothing, and I'm convinced there must be something besides light coming out of arc light. I don't know where it is.

Lt. Rubinstein: I have one more question, the G switches, are these time dependent G switches?

Mr. Bell: One had a one-second electronic timer and the other was an air damped deal with a latching air damp switch which has no electronic components at all, completely mechanical.

Lt. Rubinstein: Were these checked out satisfactorily?

Mr. Bell: Yes, most of these I believe were obtained through AEC sources and checked out thru their development. Incidentally on the case of this timer G switch on the later model Ranger, it has been replaced by a barometric switch. The air damp one still applies, the other one has been replaced by a barometric switch, I don't know for what reason, reliability I presume.

Mr. Weintraub: What I want to make are some pertinent comments. It's pretty obvious that you have a complicated system here and we're going along with these complicated systems right now. I think what is necessary for us to do is to be able to reconcile these, the conflict that I think exists between the two major philosophies in safety. One, the safety man says it will happen, in other words, the probability is one certainty, and the other is the engineering approach in which the engineer says, what is the probability of it occurring. I think it's very easy to safety any of these birds and all the missile systems right out of existence which is exactly what we're doing. I think we ought to sit down and have the intelligent approach to this thing and not resort to what I call set dogma.

Mr. Bell: Let me explain how one of these safety systems came into being. The inertia switch, the first 5 G switch we showed in here, the air damp one, did not exist in the Ranger I, II, III series. The Ranger I, II, III series was a lunar fly-by, did not have the retro package aboard, did not have the midcourse motor aboard. On the launch pad they had a heck of a time during countdown and about the fourth countdown somewhere along in here, something fired every darn pyrotechnic device in there, the solar panels unfolded in the shroud, they had quite a mess - they had to take it down and rebuild it. What if there'd been a big retro motor in there not properly safety, we'd have had trouble. That's why the G switch appeared in the next model. You're right, you can get so safe, you can't get anything done and we see it every day - it's judgment I guess, I don't know.

Mr. Taiani: For the benefit of all the people here on this RF radiation problem, the AMR is imposing one 1 watt 1 amp no-fire for five minutes. A lot of people are objecting to this, if anybody has anything better, I think they ought to get the Air Force Systems Command people into the act because they're dictating the criteria at AMR. I don't know what the Navy is going to dictate at PMR, we have the same problem there and possibly at White Sands and even at Wallops Island. This is quite a problem and there are a lot of people objecting to it, there's more to it than just the 1 watt 1 amp, there is the part about the hazard of the individual item. If enough people are available or interested, maybe we can get together some time during this seminar and discuss this very briefly.

Mr. Bell: Thank you. I think your 1 watt 1 amp is the first step toward what the gentleman said about running us right out of the business unfortunately. I didn't mean to make it quite that strong, but it's a step in that direction. It was stated recently at another safety meeting I attended that we have a conflicting business here. We're going further and further into space, therefore, we have comfort communication problems. We want devices as light as we can get them, but they have to be capable of being activated by extremely weak signals. At the same time, we're building bigger and bigger transmitters to reach them and we're throwing more energy to the poor little things that are more sensitive all the time.

A/3C Waldrop: Could it be possible that we could have in the minutes of the meeting, various publications from the Ranger program on this RF and also lightning hazard, if you have them. If not, possibly some central source where we may obtain some of those.

Mr. Bell: I do not have them with me, I can't answer for sure. As I say, a lot of them are working papers and I'll have to do some checking at home, but I'm sure some of these can be made available.

Mr. Crowder: This RF energy hazard thing, I think some comment is appropriate. The Pacific Missile Range subjects each program that comes aboard to a detailed analysis for this hazard and the Range itself prescribes safety criteria in the way of shutting down offending transmitters, changing procedures where necessary to control it. These people that conduct this analysis are available to any DOD contractor working on a program to consult without any cost involved. The second comment I'd like to make is on this so-called 1 amp 1 watt. A previous comment was made as to not knowing what the Navy's position at PMR would be. The current regulation which has not been issued, but it's in preparation now, will offer a program a choice. They may use an initiator system sufficiently insensitive that we will feel that safety is guaranteed. We think the 1 amp 1 watt is sufficiently insensitive to guarantee this. However, we are going to specify the intensity of the RF fields that you would be required to work within, then it will be necessary for

you to show that your system will safely survive this. We will put out a method of computing or test procedures that will give this qualification. This subject has been a detailed discussion of the Inter-Range Working Group which represents AMR, PMR, White Sands, Eglin, Edwards and NOTS and I think that a joint regulation in this area will be forthcoming shortly somewhat along these lines.

Mr. Paul King: Getting back to your particular vehicle, what sort of power supply do you have aboard it, what sort of capacity and output of the power supply on the thing? The electrical supply, do you have batteries aboard it?

Mr. Bell: Oh yes, we have batteries in about four different places.

Mr. King: What are they rated as?

Mr. Bell: I couldn't tell you right off-hand, I don't know. However, I could find out later.

Unidentified: This is somewhat in rebuttal to the 1 amp 1 watt. I don't want to open up old wounds, this thing is sort of being settled now. I think I am responsible for the 1 amp no-fire which I started about six or seven years ago and I must admit that that was an arbitrary choice. The reason for it was that I've been dealing with the T18 and T23 low energy detonators which took about 50 ergs to fire and so I was sort of squeamish about the firing of these things due to RF and the 1 amp no-fire was a result of data which I had gotten from HERO and other people to the effect that we could get about ½ amp floating around on the skin of Titan. So I said, well, what can the manufacturer make in the way of a squib and they said they could make a 1 amp no-fire and I said fine. Then I was worried about what would be the power requirements to set it off. Well, we pegged this at 4½ amps because of the time that we wanted the thing to function at. But I think the 1 amp 1 watt to me is completely arbitrary and it's just not based on intelligent approach to the problem and I think you can see there are pros and cons here and I think the gentleman who was talking about the idea of determining what the field is and now designing your equipment so that it will take care of the particular environment that you're in is the intelligent approach and not just being arbitrary and saying let's make it 1 amp 1 watt.

Mr. Bell: As a matter of fact, in the case of Ranger here, the most sensitive squib aboard was a .07 amp no-fire current, however, it turned out due to the configuration, the lead-wire length, shielding, etc., one of them was a 2/10ths rating and turned out to be the most dangerous, the one that was the most apt to go because it was a better antenna and less shielding, etc. You have to look at the whole system as the gentleman over here is pointing out.

Mr. Economy: Our office has recently conducted a study on lightning protection for surface launched missiles. This paper primarily deals with induction effects caused by lightning strikes and earth currents caused by a lightning strike. This paper is available, it's unclassified, and as a result of this paper, AFSC now is programming a further investigation on lightning strikes for surface launched missiles. If anyone wants to see me, I'll give you the address and you can write for this paper.

Mr. Queen: We in the Army have been plagued with this problem much the same as everyone else in Ordnance, the defunct organization. We established an RF effects committee and we too are looking for a general approach to the problem whether or not to establish some minimum no-fire level, etc. We finally came to the conclusion that the people here have apparently come to, that perhaps it would be better to take the approach of examining the stockpile to target sequence and we made an effort in this field. I think our findings are not too different than the AdHoc Committee of which DASA and the three Services and others are represented, so we've taken all of our weapons systems, particularly missiles and tried to define what we would expect in the way of fields throughout the stockpile to target sequence. Our R&D Division has published this at least in a tentative sort of a document and I suspect that this will be available for anyone who is interested in it. You might contact ORDTM, I'm not sure what the new designation is, Gil Rosenberg is the specific individual in the Command that I think is basically handling this. We might also mention the fact that we quite recently have been able to finalize and publish the results of our studies on the Hercules system. I expect that in the not too distant future, we will have a similar paper on Hawk. In this we've attempted to set out what the system will tolerate thru various portions of the electromagnetic spectrum from 70 KC I believe up to 20 gigicycles. We have actually a multi-part standard and that too is available. It's been published now in a Dept. of Army letter. Those who might be interested in that can obtain a copy of it. We have a limited supply in our particular office, AMC Safety Office, for those who are interested.

MINIMUM TEST CRITERIA
TO DETERMINE HAZARD CHARACTERISTICS OF
SOLID PROPELLANTS AND SOLID PROPELLANT ROCKET MOTORS OR DEVICES

by
R. C. Herman
Armed Services Explosives Safety Board

As you probably know, we have been working on a revision of the regulations on Explosives Hazard Classification Procedure for some time. This revision pertains to the section dealing with solid propellants. We have expanded this section considerably, and included tests to be conducted during laboratory development, propellant development, motor development, and for the complete missile.

There are specific tests to be conducted during each of the above phases. At the end of each phase of tests, there are specific instructions concerning interpretation of test results and the classifications to be assigned based on these results. We hoped to have copies of this document available for this Seminar, however, the printers advised us last Friday that the earliest date we could expect it was 15 August.

As previously stated, we have spent a great deal of time on this revision, and we have considered a number of different tests. The resulting series of tests developed are considered valid for determining storage and transportation hazard classifications, as well as for developing information on which siting criteria can be based. When the document was sent for coordination to the Military Services, we received requests to include also tests for all types of problems such as: determination of shelf life, surveillance tests, etc. I would like to point out at this time that this document is not intended to give all the answers to questions concerning whether the propellant is detonable under any given set of circumstances, or for determining effects of environment, shelf life, or these type problem areas. We limited this document to those conditions which might be expected during storage and transportation.

One particular area which has caused problems in the past, and which has been considered in this document, concerns use of standard booster or primary charges. We have taken care of this by asking the Navy to produce standard charges in accordance with specifications that we furnished. These charges will be made available to the other Services on a reimbursable basis.

As indicated previously, and in order to render assistance in determining the proper classifications, we have included at the end of each test phase a section indicating how your test results are to be interpreted and classifications assigned.

Now, I would like to point out to you that, even though this document is being printed and distributed, it cannot be considered a completed project. We would rather call it completion of the first step in this program. In this first step, we have standardized tests so that we will all be conducting the same tests in the same way. However, much work remains to be done in furnishing detailed explanation on some of these tests, particularly, when we are dealing with a complete missile. We all know that there are many other tests which could be used, but to date, there is insufficient data to validate such tests. When these tests are validated, we expect to include them in future revisions of this document. We already have several comments to consider at the next meeting of this Work Group. What I am leading up to is: after you have received this document and are working with it, don't "cuss us out" but, write down your comments or suggestions and send them forward so that we can take them up during our meetings. You people who perform these tests are in the best position to advise us as to how we can improve this document, so let us know.

Mr. Wood: I would like to ask a question. What is being done to help the operational problem on real large solid motors in the way of minimum test criteria? By this I mean 10 ft. or bigger diameters.

Mr. Herman: We got into this situation and at the time when we were working on the document that we could get very little information because this is a totally new field. We had no background to go back on as far as propellants of this size. We are attempting to gather all the available information, anything that you people come up with, we hope to include in it. But as of right now, the only thing that's in the document is that you're going to have to test full-size. This is the only thing that we could get any agreement on whatsoever. We all realize that this is going to price us out of business and we're going to have to do something better than this very shortly.

Mr. Wood: You do have in there that we have to test full size, if you do, do you have the description of the test?

Mr. Herman: Yes. I think Dr. Amster is going to talk a little on this.

Mr. Couch: I have two questions. Will the pentolite charges be available to private industry?

Mr. Herman: I understand that the system that will be used is that this will become part of the contract and that the Government will furnish them. Whether you'll purchase them thru the agency with which you have the contract or direct, I don't know.

Mr. Couch: There's much work going on that isn't part of a Government contract.

Mr. Herman: This is something that we haven't run up against. The Navy is producing them and whether they will be able to sell them directly for your own work or not, I don't know. We'll have to look into this.

Mr. Couch: The other question is, will the ICC revise Tariff 13 to be along the same lines?

Mr. Herman: Essentially right now, the first phase of this is the ICC regulations. They are attempting - I was hoping Dr. McKenna would be here - he hopes to be able to use this information that we gather as a basis for having a revision written. But as you know, it's so complicated to get the ICC regulations changed, that we have our fingers crossed. We don't know yet.

Mr. Shain: Does the new document spell out how many tests will be required on a certain motor before it will be given a classification?

Mr. Herman: It gives you a specific number of tests to be conducted during each phase and the types of tests and how to interpret the results. This is very specific.

Mr. J. A. Miller: Could you give me the number of the publication?

Mr. Herman: I can give you three numbers. This will come out as a tri-service document. TB 700-2, Army; NavWeps Instruction 8020.8 for the Navy; and TO 11A-1-47 for the Air Force. These are the same numbers of the old document, but the old document is dated 15 October 1959, the new one will be dated July 1962 and it will note that this supersedes the previous documents.

Dr. Ball: You said, if I heard you correctly, that you're going to assign these classifications to the propellant. I hope that was a slip of the tongue. There's been much too much loose talk about classifying end items by the classification of the propellant. It's just not a sensible way to do it, the end item itself has to be classified.

Mr. Herman: What we've done in this case is we've given it two classifications. In other words, you will test the propellant as a bulk grain, if you have a requirement for this, or you will test it in its final configuration and you could very well come up with two classifications, confined or unconfined. And this is all spelled out in it. There is one small point I'd like to bring out here, that I think there's a misconception on. That is in shipment of laboratory samples. There are a lot of people that are under the impression that when you ship a laboratory sample that you can only ship it from your facility to the Bureau of Explosives for test. This is incorrect. The ICC has indicated that you can ship a laboratory sample as such without tests, between your facility and any laboratory. I know this has caused a great deal of trouble in the past. If you have this at your facility, I wish you'd bring it to the attention of the people in transportation sections.

Mr. McBride: On the question of availability of pentolite boosters. The Naval Weapons Station, Yorktown can supply any commercial concern all the pentolite boosters they desire.

Mr. Herman: We have left this strictly up to the Navy to decide. I know they discussed Yorktown and Crane and Hawthorne and I think they decided that you had a little too much work down there and they were going to try Crane. I don't know what the situation is right now.

Mr. McBride: Right. The question we had earlier, was, can commercial concerns buy them separately rather than thru a regular procurement company. This can be done at the R&D Division at Yorktown.

Mr. Economy: Will the hazard classification tests require that the grain be tested in this operational configuration, as an example, a grain in a silo or whatever it is?

Mr. Herman: In other words, in this particular case, we have indicated this isn't a hazard classification, this is to develop siting criteria and this is left up to the individual service to select those tests which they want to make mandatory for their particular problems at hand. You have so many variables in this area that we couldn't say these tests are mandatory. You might have an aboveground situation, you might have an underground, you might have one missile or you might have several on a launcher, depending upon the service concerned. So there is a number of tests and each Service will make those particular ones that meets their requirements mandatory.

Mr. Jezek: In telling these people that you can ship these samples, I think it would be advisable to tell them not to exceed the weight limitations outlined in the ICC manual.

Mr. Herman: This is correct. I stated the ICC requirements for shipping laboratory samples which I think is limited to a half pound.

Mr. Jezek: I've had people call me up that had laboratory samples that weighed 5,000 pounds.

Mr. Herman: One of the questions that was asked during the break was that there has been some misconception regarding the transportation or shipment of some of these motors. Some of the companies have submitted their samples to the Bureau of Explosives for test. As you all know, the tests that are conducted by the Bureau of Explosives are on small unconfined samples. The Bureau of Explosives will come back with a letter and say, yes, this is a Class B propellant, fire hazard only. Then you take this propellant and make a finished grain in its hardware, etc. and test it for hazard classification and you get a detonation. So you class it as a Class 10 item but then turn around and say, well the Bureau of Explosives has classed this propellant as a fire hazard

and we're going to ship it as Class B. This is absolutely incorrect and in the final configuration, when this propellant is confined, if in the test it detonates, it must be shipped as a Class A and this new document will point this out to you.

LtCol A. Peczenik: I'd like to make an addendum to this radiation hazard. It has been brought out that the Navy and the Air Force are doing some surveying of microwaves and RF frequency hazards and I would like to make a little propaganda for the Army Surgeon General's office. We have a very good capability to evaluate the aspects of ionizing radiation and microwave and radio frequency radiation. In fact this work is being done by the Army Environmental Hygiene Agency. We do have a Radiological Hygiene Division which has a nuclear physicist and nuclear medical officer in charge, a bunch of electronics engineers and health physicists. They have been doing this work on a routine basis for about four or five years together with the Air Force people because many of the installations are combined installations. If you have any requests just write to the Surgeon General of the Army, please contact him for our services. We will be happy to oblige if we can.

ACCIDENT DISSEMINATION

by
R. C. Herman
Armed Services Explosives Safety Board

At our Third Annual Explosives Safety Seminar held at Riverside, Calif. last year, we discussed the possibility of having the ASESB disseminate accident information. These discussions resulted in a recommendation that a group of representatives meet with the ASESB Staff to work out details of such a program. This meeting was held and it was decided that accident reports would be forwarded to ASESB for dissemination. The group decided that distribution to Service facilities would continue to be made through the Service Headquarters. A letter implementing this program, and inviting participation, was sent to all companies represented at the Seminar (there were approximately 50 companies), in September 1961. Thirty eight companies responded, either by letter indicating their willingness to participate or by submitting accident information for dissemination. I would like to point out, however, that of the 38 companies which expressed a desire to participate, only 10 companies have furnished information on their accidents. Since no unfavorable responses were received, and in order to give sufficient time to acquaint those companies from which no response was received with the type information being disseminated, distribution of accident information has been made to all companies invited to participate. As of 24 July 1962, a total of 110 incident reports have been disseminated. These include those received from the 10 companies, the Government, and the Manufacturing Chemists' Association. Of the 110 incidents, 78 were explosive, 15 were potential, and 17 were operational involving hazardous materials.

We would like to point out that the success of this program in the overall exchange of accident information depends on the response made by your companies in sending us your accident information to disseminate. We are disseminating all reports we receive, within security limitations, however, this program is only as good as you make it. We would appreciate it if you would personally check with your appropriate departments to encourage response in sending in your accident information in order to fulfill the original purpose of this program for enhancing safety for all. We would also like to point out that, as indicated in our September 1961 letter, this program is not necessarily limited to those companies represented at our Seminars, and any other companies in the propellant business which desire to participate may do so by contacting the ASESB. Thank you.

AN EXPLOSIVE HAZARD CLASSIFICATION SYSTEM FOR SOLID PROPELLANTS

by
R. L. Parrette
Aerojet-General Corporation
Sacramento, California

I. INTRODUCTION

With the advent of newer, highly explosive ingr .ents in propellant formulations, it becomes increasingly important that the susceptibility to explosion of the propellants be known at an early stage. Whereas a few years ago the common practice was to thoroughly characterize the propellant only when it was committed to full-scale production or to use, it is now necessary, for full assurance of safety to personnel, to know the explosive tendencies in the early research or development stage. From this knowledge the decision is made whether desensitization of the propellant is one of the main development problems, and also whether research and development is to be carried out remotely, manually, or some compromise between remote and local handling.

The Aerojet-General Corporation has established a classification system which includes five types of propellants with an increasingly higher order of explosive hazard. This presentation starts with a brief description of the explosive susceptibility tests that are used in arriving at the classification system. The types are then defined, and a working set of rules governing permissible remote or manual handling for each type is then shown. An application of the type classification and the working rules to a typical high-energy system is then presented. Finally, the shortcomings and limitations of the classification system are described, and future plans for improvement of the system are discussed.

II. DESCRIPTION OF EXPLOSIVE INITIATION TESTS

Three explosive initiation tests are used in the classification scheme. The first and most severe of these, shown in Figure 1, is the Card Gap Test developed by the Naval Ordnance Laboratory. This test uses a comparatively large propellant specimen, about $1\frac{1}{2}$" in diameter and weighing approximately 0.6 pounds.

Figure 2 shows a scaled down explosive initiation test that is used at Aerojet-General, in which the propellant specimen is $\frac{1}{2}$" in diameter by 2" long. This test is used with or without the tetryl booster shown in the figure. The small specimen has proven very useful for propellants in which a small critical diameter is known or suspected.

Figure 3 shows the setup for the ICC detonation test, in which a 2" cube of propellant is subjected to a No. 8 blasting cap, with the propellant mass being completely unconfined.

III. EXPLOSIVE CLASSIFICATION TYPES

The propellant types are defined as follows:

Type 1 Propellants - Type 1 propellants are characterized by (1) proof of negative results at ambient temperature on the NOL Card Gap Test with zero attenuation, and (2) an autoignition temperature greater than 450°F. Conventional composite propellants, made up with non-explosive plastic binders, inorganic perchlorate oxidizers, and aluminum metal powder as an additive almost universally fall into Type 1.

Type 2 Propellants - Type 2 propellants are those which are negative in ICC detonation tests, negative in the ½x2" detonation tests with 5 gm tetryl booster, but are positive in NOL Card Gap Tests at zero attenuation. The propellant will also show normal burning in the ICC test in which a 2" cube of propellant is ignited, and will exhibit an autoignition temperature greater than 350°F. Propellants in which commercial explosives are used as oxidizers frequently turn out to be Type 2.

Type 3 Propellants - Type 3 propellants are negative in ICC detonation tests, positive in ½x2" detonation tests with 5 gram tetryl booster, but negative without booster. The propellant will also show normal burning in the ICC burning test and exhibit an autoignition greater than 350°F. Propellants with a high content of commercial explosive as the oxidizer are often Type 3.

Type 4 Propellants - Type 4 propellants are negative in the ICC detonation test but positive in ½x2" detonation tests without booster. The propellant will also show normal burning in the ICC burning test and exhibit an autoignition greater than 350°F. Some propellant formulations with organic crystalline types of oxidizer have been classified Type 4.

Type 5 Propellants - Type 5 propellants are those which are positive in the ICC detonation test, or which show abnormal burning in the ICC burning tests, or exhibit an autoignition less than 300°F. Some propellants with organic perchlorate type oxidizers have been classified Type 5, particularly at high solids loading.

Type U Propellants - Type U propellants (unknown, or unclassified) are formulation types which are unknown in their characteristics and have not been evaluated and placed in a number type. Evaluation is done by conducting remote control propellant mixing and testing in step-wise scaleup from the 5 gram to the 1 pound level. Type U

propellants are always treated with the utmost precaution until they have been classified in a numbered type. If the safety tests do not serve to classify the unknown propellant within Type 1 - 5 inclusive, the propellant shall maintain the U classification, and a special set of working rules will be drawn up regarding its handling.

Summary - If the type classifications are put in chart form, the result will be as in Figure 4. Here it is seen that the key test for identifying a propellant as Type 5 is a positive result in the ICC detonation test; for Type 4, the key test is a positive result in the ½x2" cylinder without booster, and so on.

IV. WORKING RULES FOR PERMISSIBLE OPERATIONS, BASED ON THE CLASSIFICATION SYSTEM

In Figure 5 is shown an example of the working rules which evolve from the type classifications given above. The examples given in the Figure are just a small portion of the whole; actually, 25 distinct unit operations are to be found in the entire chart.

Propellant mixing, with very powerful mixers having close clearances and heavily loaded propellants, is almost always regarded as a potential hazard. Only the well-known Type 1 propellants are mixed with exposure of the operators to the mixer, and then only on a laboratory scale.

Casting operations which do not shear or impact propellant are a lesser degree of hazard than mixing, and so the operation is permissible for manual control for Types 2 and 3. However there are shearing operations which must be guarded against, such as closing metal casting valves in which propellant is wedged between the valve and the valve seat.

Scraping down of the mixer and removal of the core from the cured propellant are operations which can induce a high level of local shear, and so they are conducted remotely for all propellants except Type 1.

Machining propellant with a stream of water playing on the cutting tool, and with operators present, is restricted to Type 1 propellants, until such a time that it has been demonstrated by remote experiment to be safe for higher classification types. Propellant machining without the stream of water is done remotely on all types of propellant.

V. APPLICATION OF THE TYPE CLASSIFICATION TO A NEW PROPELLANT SYSTEM

Figure 6 shows a "case history" in which a new propellant was carefully classified and scaled up in accordance with the system of hazard-type classification and accompanying working rules. This particular propellant appeared dangerous at the outset, as evidenced

by the low impact stability values obtained with the drop hammer. Further testing showed the propellant to be Type 3, whereupon it was scaled up under remote handling conditions as required by the working rules until it was ready for test firing. At this point the hazard from accidental dropping of test motors was assessed by conducting drop tests from a height of 40 feet. Negative results were obtained in the drop tests, so the propellant proceeded to ballistic testing in sub-scale motors. These firings are in themselves some indication of the safety of the propellant, so further scaleup to production-size batches is feasible, pending further replicate rough-handling tests and acquisition of remote operation procedures and equipment as dictated by the working rules. An alternative course is to attempt to reformulate the propellant so as to obtain a lower hazard classification.

VI. SHORTCOMINGS OF THE HAZARD CLASSIFICATION SYSTEM

The chief objection to the hazard classification system is that the stress levels imposed on the propellant in the explosion initiation tests cannot be related to the stresses encountered in propellant processing and firing. For example, the propellant machining foreman says, "Yes, it is interesting that this propellant does not detonate from a blasting cap and 5 gram tetryl booster. However, that doesn't tell me whether or not I can safely face off the end of the propellant grain with hand-trimming tools." Similarly, the test division engineer says, "You tell me that this propellant will not detonate in the NOL Card Gap Tests. Does that mean that it will not detonate if one of my clumsier operators drops it off the bed of a truck?"

To put the questions differently, is there a scientific basis for setting up the permissible working rules from the type classification, or is it strictly arbitrary? The answer is that the working rules are quite arbitrary and quite conservative, but they become less so as more experience and more rough handling data are obtained on a given propellant. The 40' drop test mentioned in Figure 6 is an example of this kind of data. Two other examples are the rough machining tests, photographs of which are shown in Figures 7 and 8. This machining is done under remote conditions, at excessive tool speeds and with cutting edges more dull than would be tolerated in actual operation. If prolonged testing of this nature does not result in ignition or detonation, the propellant is considered safe for machining under standard conditions.

VII. FUTURE PLANS

Plans for improvement of the hazard classification system are to supplement it, or perhaps replace it, with sub-classifications based on results obtained in rough handling or rough machining tests of the type described above. These tests will be standardized and made reproducible insofar as possible. It will also be necessary to develop

NOL CARD GAP TEST

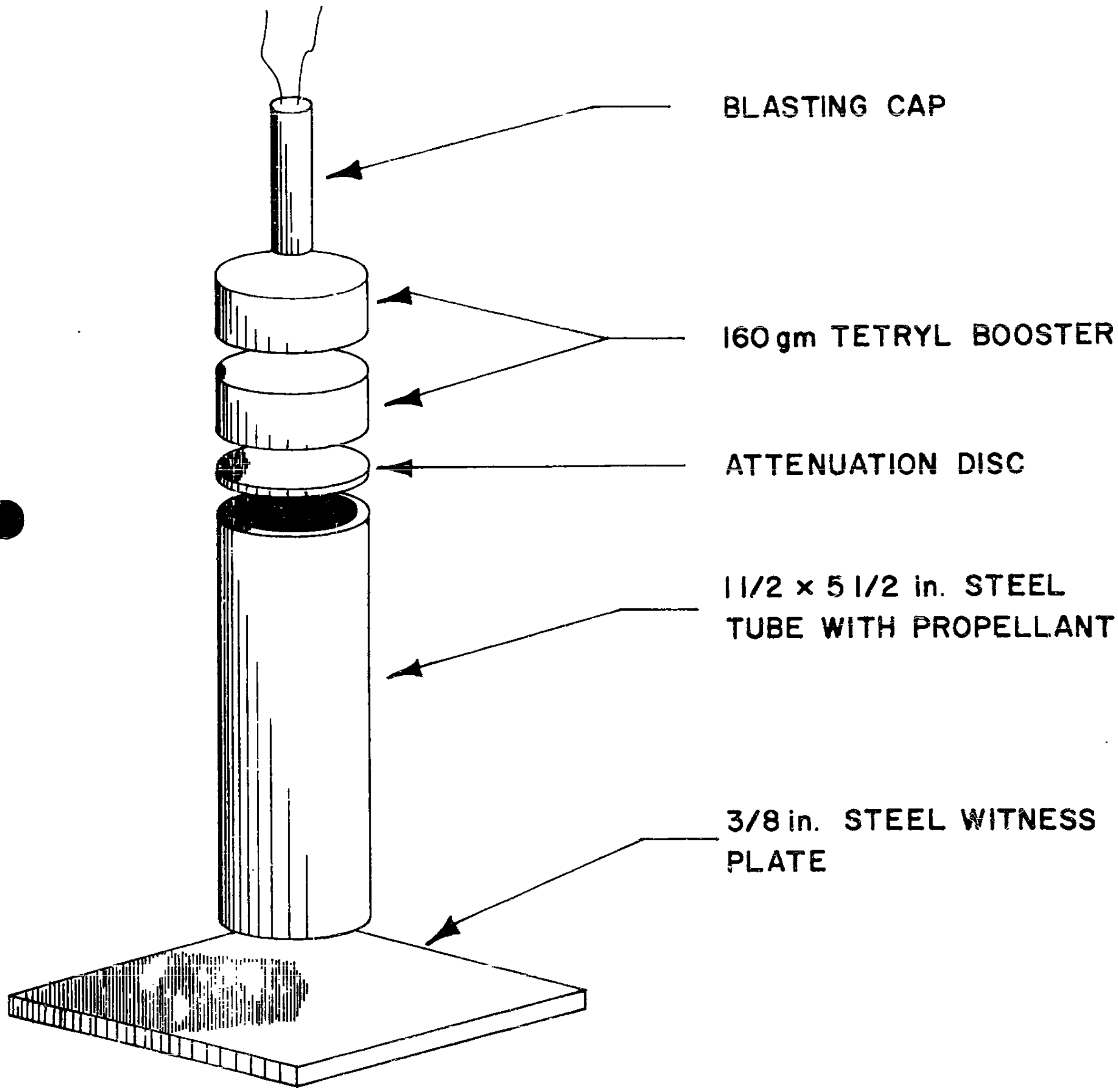


Figure 1

SMALL-SCALE DETONATION TEST

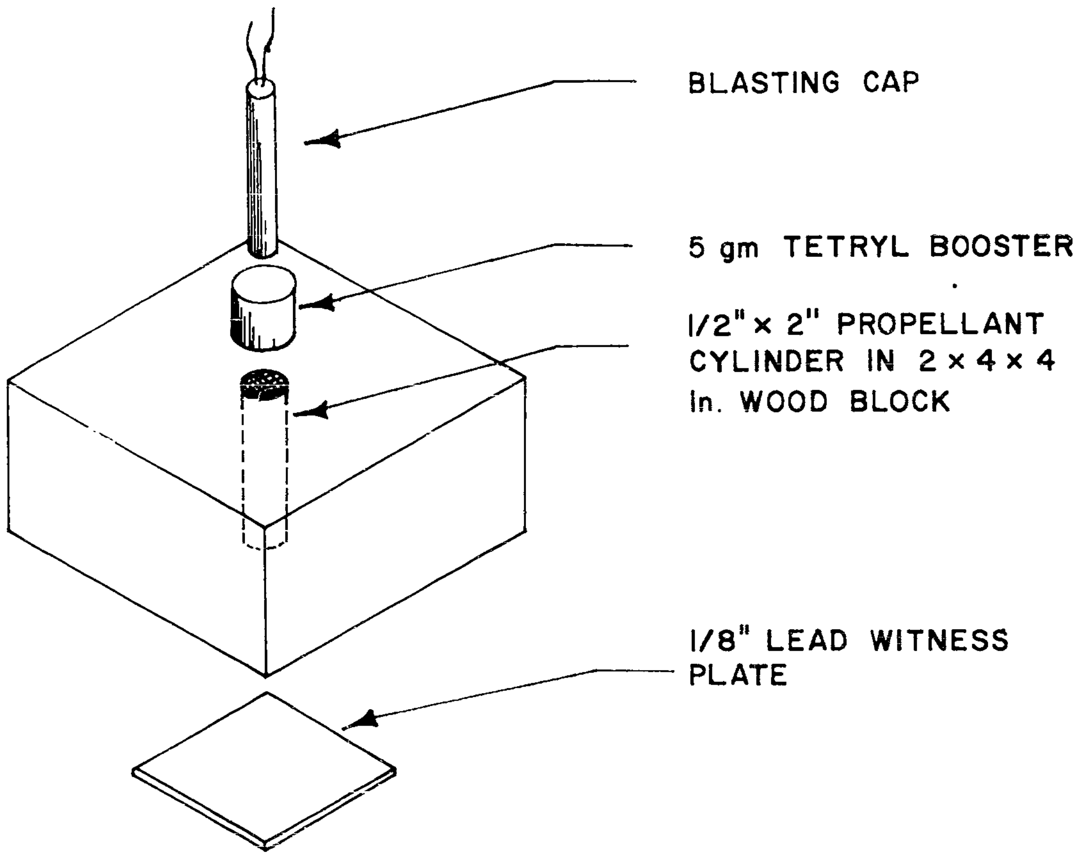


Figure 2

ICC DETONATION TEST

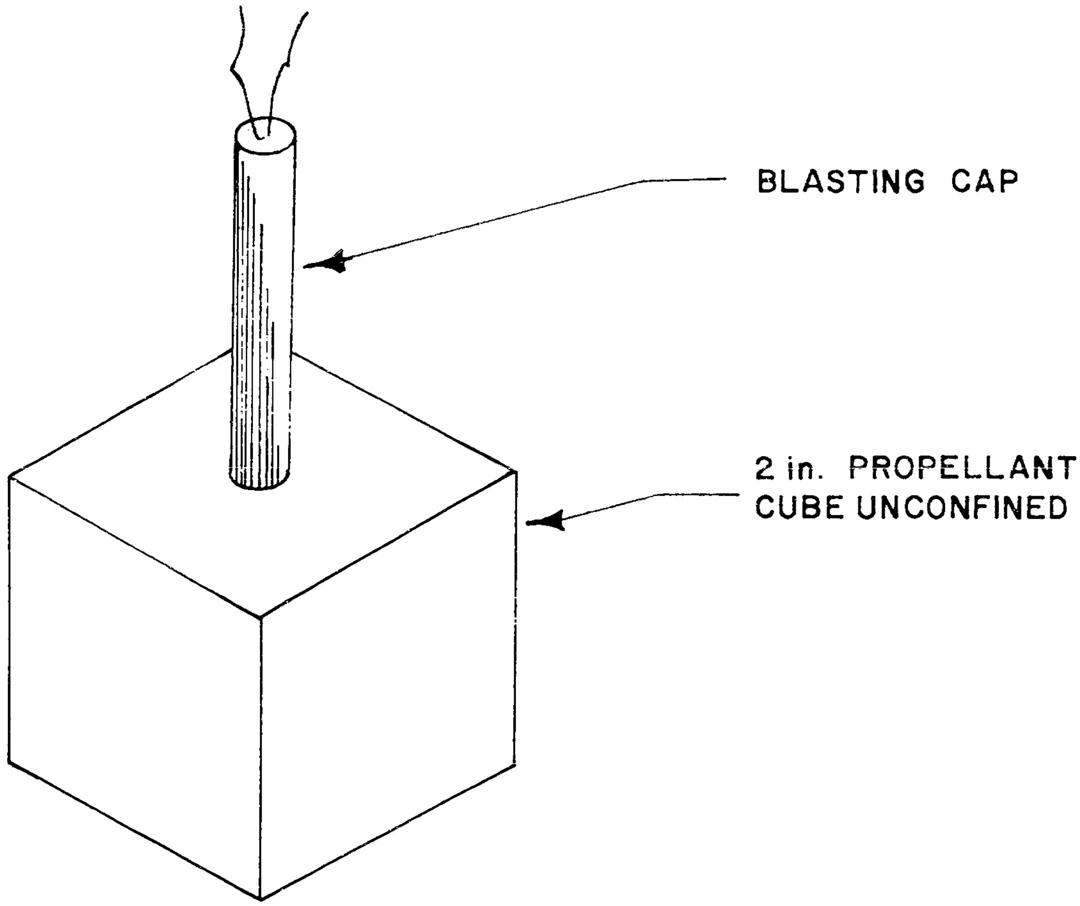


Figure 3

	Type				
	1	2	3	4	5
ICC Detonation Test	-	-	-	-	+
1/2 x 2-in. Cylinder Without Booster	-	-	-	+	+
1/2 x 2-in. Cylinder with Booster	-	-	+	+	+
NOL Test, No Attenuation Cards	-	+	+	+	+
Autoignition, °F	> 450	> 350	> 350	> 350	< 300

Figure 4. Key Tests in the Classification System

PERMISSIBLE OPERATIONS FOR PROPELLANTS OF VARYING HAZARDS

UNIT OPERATIONS	1	2	3	4	5	U
PROPELLANT MIXING	X /	/ X	/ X	/ X	/ X	/ X
CASTING OPERATIONS WHICH DO NOT IMPACT THE PROPELLANT	X /	X /	X /	/ X	/ X	/ X
SCRAPE-DOWN OF MIXER	X /	/ X	/ X	/ X	/ X	/ X
REMOVAL OF CORE	X /	/ X	/ X	/ X	/ X	/ X
PROPELLANT MACHINING, WET	X /	/ X	/ X	/ X	/ X	/ X
PROPELLANT MACHINING, DRY	/ X	/ X	/ X	/ X	/ X	/ X

PERMISSIBLE, MANUAL

PERMISSIBLE, REMOTE ONLY

Figure 5

SCALE-UP OF NITRATO-PLASTICIZED POLYURETHANE PROPELLANT

	Size of Batch				
	1 gm	50 gm	1-lb	10-lb	60-lb
Experience, batches	15	4	25	15	1
Impact stability, cm/2kg	5	7	7	7	7
ICC detonation test	None	None	Neg.	Neg.	Neg.
1/2 x 2-in. cylinder without booster	None	Neg.	Neg.	None	None
1/2 x 2-in. cylinder with booster	None	Pos.	Pos.	Pos.	None
NOL Card Gap, attenuation, in.	None	None	$>1\ 1/2; <2$	$>1\ 1/2; <2$	None

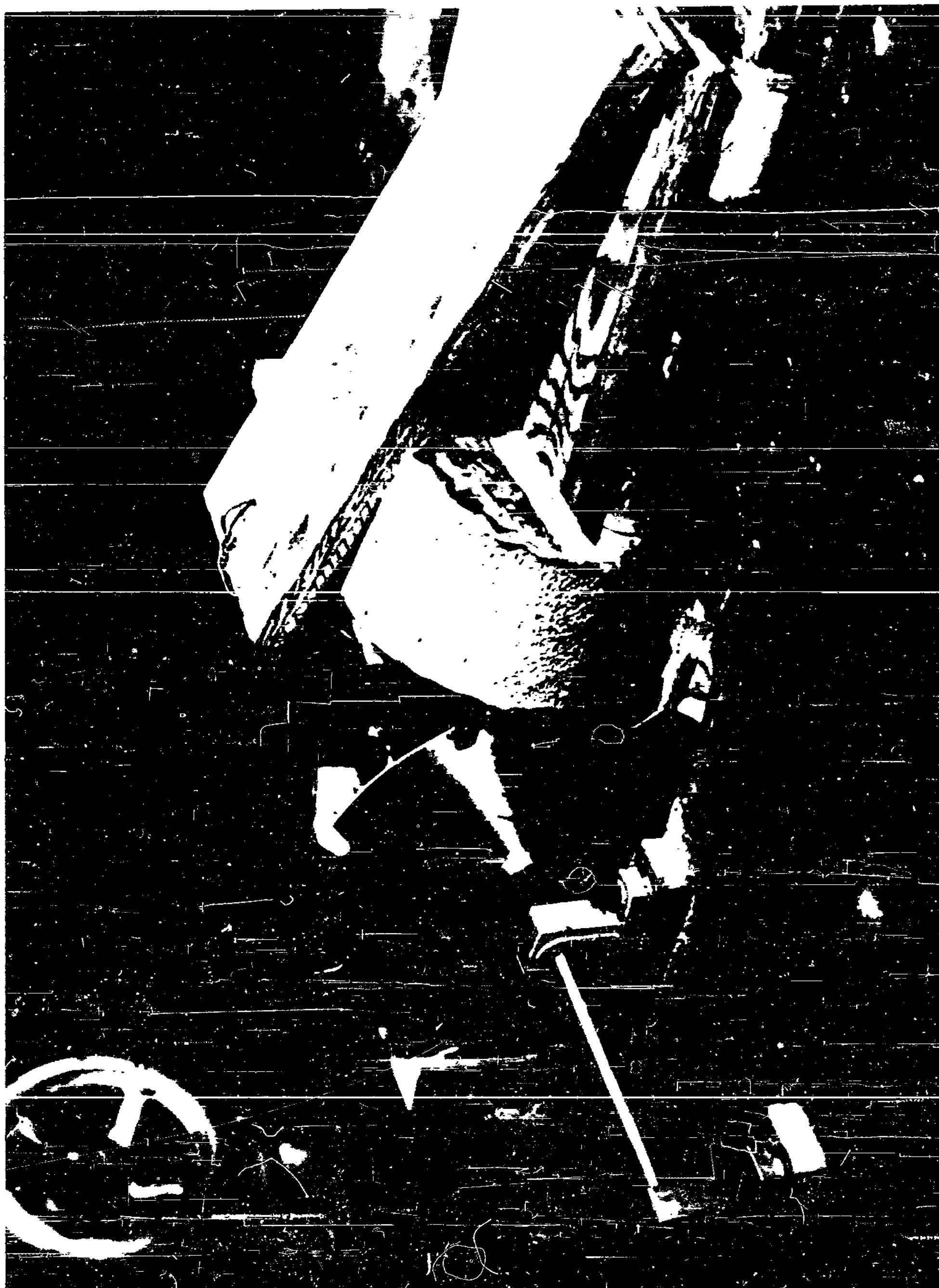
Figure 6, page 1 of 2

SCALE-UP OF NITRATO-PLASTICIZED POLYURETHANE PROPELLANT

	Size of Batch				
	1-lb	10-lb	60-lb	150-lb	2200-lb
Experience, batches	25	15	1	None	None
40-foot drop test:					
(a) 1-lb in micarta sleeve	Neg	None	None		
(b) 6-lb test motor	None	2 neg.	None		
(c) 20-lb test motor	None	1 neg.	3 neg.		
Motor firings					
(a) 6-lb motor	None	4 normal	None		
(b) 20-lb motor	None	1 normal	None		
(c) 100-lb motor	None	None	None		

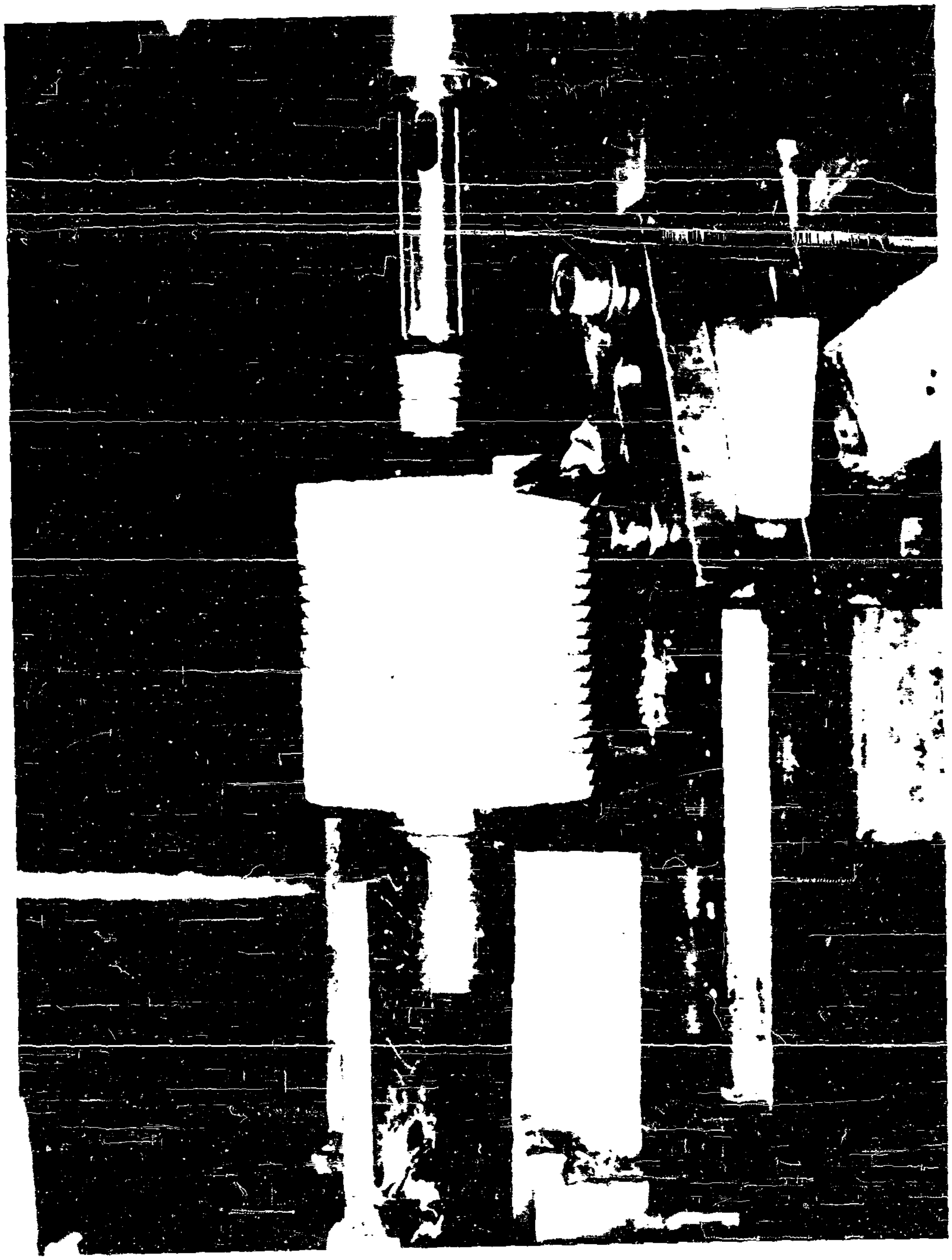
Figure 6, page 2 of 2

UNCLASSIFIED



Radial Saw Test Arrangement
Figure 7

UNCLASSIFIED



Typical Arrangement for Propellant Peripherial Machining

Figure 8

tests for special, new propellants in which the chief hazard is accidental ignition, rather than accidental detonation. Sub-classifications based on a variable and calibrated friction tester are needed.

Studies are also in progress attempting to compute the energy of the explosive initiation in absolute physical terms, and to correlate this energy with such parameters as the hardness and the heat transfer coefficient of the propellant.

Dr. Shuey: Assuming that there is some merit to this test which I somewhat doubt, it bothers me that the two first tests that you have for personnel exposure, you're dealing with a liquid, you're running all your sensitivity tests on a cured final propellant. And I wonder if there's much correlation between your critical diameter which you're measuring and the solid form on which you base all of these five factors and what you actually have in the mixer when you're exposing the operator to a scrapedown.

Mr. Parrette: We not only run them on the cured propellant, we run them both cured and uncured. So far we haven't detected a significant difference. When we do of course the system will have to be looked at again. But when we speak of a classification, we're referring to the classification the propellant has in the cured state and I neglected to mention that we have also tested it in the uncured state. We neglect that because so far we haven't seen serious discrepancies between the two states.

Dr. Shuey: We found something like a 10 to 1 difference in critical diameter. The double base slurry has a critical diameter on the order of 1/8" to a quarter inch perhaps where a cured is greater than 1".

Mr. Parrette: Although our tests are at a different size of diameter, we are not evaluating critical diameter as such. Most of these new exceptionally hazardous beasts, we find the critical diameter is small, actually less than the ½" diameter of the small block tests.

Mr. Jezek: On your ICC detonation tests, what size cap do you use, is it a shaped charge cap and how many times have you had the propellant detonate based on the configuration that we saw in your slides?

Mr. Parrette: The No. 8 blasting cap is a shaped charge to some degree. Our type 5 propellants are unmistakably positive in this test, every time we run one it's positive. We have more than one propellant system which has come out type 5.

Mr. Jezek: And do you use the ICC detonation test first and if you do, and if you get a positive result, do you go on and test with the other

items that you use? In other words, I can't see if you get a detonation on your ICC, why bother with a card gap or anything else? Because we know that the thing will detonate with ordinary blasting caps.

Mr. Parrette: We generally do not start with the ICC detonation tests, we generally start with the smallest test described here, the ½x2" cylinder and we start there because it's sort of a mid-point in the classification scheme and moreover, it's the smallest size sample and that's the scale we're working on when we first start worrying about what class the propellant is.

Mr. Jezek: It seems to me that there appears to be a difference of opinion as to what we call hazard classification, type classification and sensitivity of propellants. It seems to me that I wouldn't use an ICC detonation test to find out the sensitivity of your propellant, but it seems to me that's what you're doing out there.

Mr. Parrette: Well, the ICC tests certainly must be run at some point if the propellant is going to go anywhere. That is, if it proceeds in development, you necessarily have to run it to satisfy the ICC. Some of these tests do seem to be a little out of order, for instance, it's been suggested that the ICC test has a fairly large diameter compared to our half inch diameter for the small wood block tests. Our only position there is that perhaps a slight degree of confinement that the wood block imparts to the specimin is enough to make that difference and as to the propriety of the order of our classification scheme, about all I can say is that we have had propellants that fit that order and we have examples of propellants in each of these type classification. We haven't yet found one that correlates the classification scheme, i.e., which is positive in a test which would be assumed to be negative based on a more severe test run prior to that.

Maj. Eberle: Has your company done anything at all in these large diameters, I don't mean large by 2", I mean large by 10 ft. to classify these things. We are in the process of buying a 10 ft. diameter booster and we're having an awfully difficult time getting this thing classified because nobody knows what tests to make.

Mr. Parrette: Yes, we have performed some large diameter critical diameter tests. Could Mr. Paulson or one of the Downey men answer this question.

Mr. Paulson: The largest test we have performed to date is the 19" diameter cylinder in a half inch of steel. Now, we would like to do larger tests to get more information, we have not done that as yet. Is there a specific question that I can answer for you. We'll see you later.

Mr. McCay: I just wonder if there has been any correlation made between this test data and quantity-distance requirements?

Mr. Parrette: No, we have not. The explosive force calculated and ballistic mortar lead block calculated values for most of these high energy propellants are quite similar and if they go off, we assume that the explosive force would be in the neighborhood of 160% of that of TNT and our quantity-distance barricaded table is set up on that presumption. The remote operations lab discussed yesterday makes the same assumption.

Mr. Weintraub: I think I can answer the gentleman's question as to why you run the card gap test instead of the ICC test. Not being a propellant manufacturer, I think I am free to say this. You just don't want to wash your dirty clothes out in public, so what you do is do it at home and when you find you can do something with the thing, then you send it down to ICC, as sort of a rig test.

Mr. J. A. Miller: Have you found any correlation between the drop test and the cap test that you are running, any one of them?

Mr. Parrette: Only one instance, a type 5 propellant, highest hazard classification has gone off in this 40 ft. drop test. We haven't gotten positives in lower types.

Mr. Miller: I was referring to the Bureau of Mines drop test.

Mr. Parrette: We run the Bureau of Mines drop test when first we're operating at the 10th gram level. We regard it as a danger signal only, we do not attempt to classify or dictate working rules based on the drop hammer test because it's proved so misleading in the past. Some propellants which are in the production stage have a drop value of 6 centimeters with the Bureau of Mines apparatus.

THE HAZARD CLASSIFICATION OF LARGE SOLID PROPELLANT MOTORS

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I Introduction

On July 17, 1944, at Port Chicago, California, three and a half million pounds of explosives in railroad cars and in the holds of a ship exploded[1]. Three hundred twenty persons were killed, 390 were injured, and property damage was estimated at $13,000,000. Among the injured were two persons 8 miles away; each lost the sight of an eye.

Approximately three weeks later a 20-kiloton atomic device was detonated over Hiroshima[2]. Equivalent to approximately 40 million pounds of TNT, it destroyed a 4.7-square-mile area, left 70,000 injured, and an equal number killed or missing. Assuming that the blast effect of an explosive is proportional to the cube root of its weight, this bomb was only 2-1/4 times as powerful as the Port Chicago explosion.

One specific stage proposed for the NASA space program utilizes 3.7 million pounds of solid propellant[3]. Restricting ourselves, for the moment, only to the blast effects, let us predict the consequences of the detonation of such a mass. Assume that the explosive effect of the propellant is equivalent to that of an equal weight of TNT (ignore the conclusion that damage is a function of energy release[4] and that the energy potentially available for standard composite propellants is greater than that for TNT). The particular design[3] considered has a mean height above the ground of 37-1/2 feet for which the reflection coefficient[5] is 1.4 and the blast is equivalent to that of 5.2 million pounds of TNT. The approximate peak pressure resulting from this explosion is shown in Fig. 1, as a function of distance from the explosion. (The data have been calculated from information given in reference 5.) At 12,000 feet the

peak overpressure is 0.65 lb, the maximum exposure pressure recommended for inhabited buildings. Accordingly, if we must anticipate an explosion of this magnitude, say at a launch site, operations during any hazardous operation must be restricted or curtailed within a 12,000-foot radius.

Even this superficial analogy must conclude that the possibility, no matter how remote, of explosion of such a system cannot be ignored. No doubt, the nation's drawing boards have designs for even larger, more energetic systems.

To propose the necessary precautions, one must begin with an analysis of the situations in which these large systems are being used or might be used, the hazards which might be expected in these situations, and the possible results. Such a study will give responsible management an estimate of the risks associated with a particular action. The choice among several possible courses of action is a management decision which cannot be delegated. A brief study of the type outlined is now being made by SRI's Propulsion Sciences Division. The study concerns only NASA space missions, and to limit the area of the investigation, we have confined ourselves to studies of conventional composite propellants containing neither detonable binder nor other detonable ingredients. Nor have the possibility and consequences of enemy action been considered. It is appropriate to emphasize at this point that safety is not being considered. By "safety" we mean that area concerned with protective measures: how thick a wall should be, how many men can work safely or ought to be exposed under a hazardous set of circumstances, etc. Lastly, we have not treated the problem of acoustic hazards. For a consideration of this aspect as it relates to the blast problem reference can be made to the report of Ullian (30).

It will be shown that segments of large motors may be transported according to ICC regulations for Class B systems. They present only a fire hazard. Completely assembled monolithic units, since they may explode or become propulsive, must be treated as Class A. At all other times they both may be considered as Class II explosive systems

except that, when fully armed or when the upper liquid stages are being fueled or are already fueled, they must be considered as Class X.

II To What Hazards Can a System be Exposed

The entire process through which a missile system passes in going from the manufacturer up to and including the immediate post-launch period can be conveniently, if arbitrarily, divided into five phases:

1. Shipment from the motor manufacturing plant to the receiving point.
2. Transportation at the receiving point.
3. Assembly, check out, and storage operations.
4. A period when the motors are on the launch stand and during which the normal pre-launch operations are being carried out.
5. A period immediately after launch, when the vehicle is still in close proximity to the launch pad and inhabited buildings.

Let us now direct our attention to each phase.

A. Shipment from the motor manufacturing plant to the receiving point.

As a first step the system must be lifted, probably by crane, onto some kind of transporter. This transporter may be directly suitable for use as a trailer for crosscountry travel or may, in turn, be loaded onto a railroad car, truckbed, barge, or airplane. Certainly even these may be specially designed for the task. For large monolithic systems it has been proposed that somewhat different techniques be used [3]: "In essence, the large weight of the motor would be borne for all transportation purposes by water. The motors would be cast in a floodable basin. For shipping, a caisson around the motor would be sealed, the basin flooded, and the container floated onto a special,

partially submersible barge. The barge is brought to normal attitude and towed to the launch facility."

With very little deliberation it becomes apparent that the following might occur:

a. a winch might fail and drop a stage or segment

b. a winch operator, through oversight, incompetence, or malicious intent might drop the unit

c. as a result of one or the other of the above, or of inadequately designed equipment, the unit might hit the transporter or be squeezed or otherwise damaged as it is lowered into position

d. during transportation constant vibration and severe jolts, as from "bumping" of railroad cars, might cause damage

e. at any time the unit might become the target, by design or accident, for small arms fire

f. train, highway, and other accidents are possible

g. temperature control devices might fail

h. proximity to other accidents and attendant risk is always a possibility: electric storms, nearby fire, or explosion, etc.

i. for seaborne or airborne systems the usual environmental hazards are present: storms, sinking of a barge, plane crash or explosion.

In similar fashion we arrive at considerations regarding possible mishaps for each of the remaining phases.

B. Transportation at the receiving point

With adequate planning, it is possible to design transportation equipment to minimize the number of operations involved when a small motor, stage, or segment is received at the launch site. For example, it should be possible to store each unit upon or within the transporter

on which it is shipped. In general, traffic on a military or similar base is far more readily controlled than elsewhere. Accordingly, the probability of an accident is appreciably reduced.

For the large, monolithic motors [3] the barge after being brought to the launch facility "is partially sunk, the caisson towed off, and maneuvered to the location of the launch pad. Water is removed from the launch basin and the motor caisson is maneuvered into the proper vertical position for launching the Vehicle". Most, if not all, of the operations associated with this procedure are new and untried. It is therefore, patently impossible to predict many of the associated hazards; here, experience will be the best teacher. Nevertheless, for monolithic and for the more readily transported smaller or segmented units, most, if not all, of the situations itemized in the preceding section are applicable. In addition, since these units are now in the vicinity of other propulsive systems at the launch facility, the possibility of a malfunction of an adjacent motor (solid, liquid, detonable, etc., with its associated dangers must be considered).

C. Assembly, checkout and storage operations

Once again any necessary movement exposes a motor to some of all of the hazards previously enumerated. In addition, certain conditions are peculiar to assembly, checkout, and storage operations.

Although monolithic units, by definition, eliminate the assembly manipulations, they have, as indicated above, their own problems. Segmented units must, of course, be assembled as must the complete, but individual, units of a whole multi-motor stage. For this, special structures will undoubtedly be required. One type which has been suggested resembles the familiar pile of dishes seen in cafeterias. Here the pile is supported by a below-surface spring and, as each dish is added, the stack drops a small amount. With a similar arrangement it is foreseeable that each segment need be lifted only a small distance above ground level and carried until it is just above the segment to which it is to be fastened; then it may be lowered gently into place and assembly operations completed.

An alternative suggestion requires above-ground assembly within a superstructure of several decks. Each unit would be lifted into place and assembled.

An important problem here is that individual segments must now be carefully mated to each other at precisely machined and closely fitting interfaces. Unless these surfaces have been scrupulously cleaned and inspected it is possible that some propellant might be trapped and subject to compression, shear, and other grinding forces.

This is also the first time during which large masses of propellant are brought into close proximity. This has a bearing on thermal stability and detonability of explosion problems which will be discussed later.

Complete assembly requires the completion of a number of subassemblies. Among these are the destruct systems, and other devices which include explosive elements. This is the first time, since having left the manufacturer, that these explosive charges will be involved directly. A mishap here is always a possibility.

Except for the immediate pre-and post-launch periods, the phase during which the entire assembly is being checked presents the greatest real hazard. By this time, except for some last minute insertions of ordnance items, the rocket is completely assembled. It may include as much as 30 to 40 pounds of high explosives much of which is in the form of detonating cord or shaped charges whose sole purpose is to destroy the motor case. The nozzle is now attached, if this was not previously done. Premature ignition renders the unit propulsive. A very large number of the necessary "checkout" tests require passing significant electrical current through each of many components. Mistakes in wiring are not uncommon. Induced currents and other stray effects are present. These may effectively actuate the ignition or explosive devices.

The checkout period is also a time for making repairs, modifications or performing other operations upon the assembled system. Unless otherwise forbidden, these may involve the propellant, ignition or ordnance systems with the attendant safety problems.

Storage is, by definition a period or quiescence during which no operations are being conducted, but it not a time for relaxation. The hazards of large masses of propellants within each rocket are augmented now by their close proximity to other propulsion systems. Under normal

circumstances self-heating [6] occurs at a very slow, probably negigible, rate. As the temperature rises so, too, does the rate of spontaneous decomposition. At high enough temperatures, explosion results; otherwise severe degradation is possible. This behavior is size-dependent: larger systems self-heat more rapidly. Consequently temperature control is a necessity. Failure of the control system presents a possible hazard which may not materialize until the actual launch phase.

Whether the moving of the completely assembled system to the launch stand is to be considered part of the assembly or of the pre-launch period is unimportant for our purposes. Here again, whether monolithic or segmented, the techniques for moving such large systems (200 to 400 feet or more high) have not yet been developed. Certainly it is not inconceivable that such a large motor might topple, a gantry might derail, a nearby blast might knock it over, unanticipated instability might develop, overloaded structures might fail. For systems moved by barge similar considerations apply.

One possibility is that final assembly and checkout might be accomplished on the launch stand proper. Though this might sharply reduce the total number of operations involved in preparing a rocket for launch, it has major disadvantages: the launch platform is unavailable for other use for a much longer period of time, and the rocket being assembled is closer to other units and therefore more exposed to the possible malfunctions.

D. Pre-launch period

Pre-launching is the period in which the completely assembled unit is on the launching platform, in position, and being made ready. It is the period during which the final checkout and countdown commence.

Significantly it is also the period during which the liquid upper stages, if any, are filled with their energetic, often cryogenic, contents. It is neither our function nor our intent to delve into possible causes and the probability of malfunction of these units. We shall assume that "if it can happen, it will happen." The record shows, too, that 20% of attempted launches abort on or near the pad [8]. For a hydrogen-oxygen

system, the possibility of explosion or detonation is always possible. The consequences range from the resultant flying metal shrapnel and a high temperature fireball, up to and including a high pressure shock wave; any of these consequences may reach the solid first stage.

During this period the rocket, if not the highest object, is one of the higher ones in the immediate vicinity. It is a natural target for lightning. At some stage in the proceedings igniter squibs are installed, and explosive units may be armed (if not already). Nearby sources of electromagnetic radiation or other powerful signals may activate these units prematurely. An error in routine electrical checkout, or a path through an unknown ground loop may do likewise.

This is also the last opportunity for repairs or modifications. As during the checkout period these may involve hazardous operations on the propellant, ignition, or ordnance items.

E. Ignition and immediate post-launch

During this ultimate operation a special condition exists. Until this moment everything humanly possible has been done to protect the rocket from any thermal or mechanical excursion. Now the grain is ignited, and the system subjected to powerful accelerating forces. If the ignition system malfunctions the interior of the grain may be subjected to too extreme a pressurization rate or to too high an ultimate pressure. The grain may crack or, worse, may shatter to expose more area to the combustion zone than that for which it was designed.* Assuming the system performs correctly ballistically the guidance may malfunction and, once in the air, the now propulsive rocket may turn back towards earth and, perhaps, too soon for the safety officer to destroy the unit. Perhaps, destruction can be accomplished and the rocket rendered nonpropulsive by fragmentation of the case and grain. The fragments of burning propellant will fall back to earth.

*Faulty inspection may permit an already cracked grain to reach this stage.

This completes our list of the hazards to which a large solid propellant motor may be exposed. It is complete? Most assuredly it is not, for, if the history of safety engineering teaches us anything, it is that we, as human beings, cannot anticipate all possible causes of accidents.

III To What Hazards Have Systems Been Exposed

Having performed the mental exercise of trying to predict malfunctions and accidents, it is useful to compare our abstract predictions with history--what accidents have befallen rockets, and are there any we have not predicted?* Unfortunately, scientists and engineers, being human, brag about their successes. Failures don't seem to be reported regularly. Some, however, are on the record.

Are there examples of accidents which, though anticipated, have never occurred? Is the sample large enough--our experience broad enough--to conclude that these will not occur?

Our experience with large solid motors is restricted largely to Polaris and Minuteman. One Polaris motor rolled off a truck. Another truck carrying a Polaris hit a snowbank. Both motors were x-rayed, found to be undamaged, and satisfactorily fired. The temperature control mechanism in one Polaris container failed during freezing weather; the motor was x-rayed and found to be undamaged. It has not been fired. The temperature control of another Polaris unit failed and the unit reached a temperature of 170°F for an indeterminate period less than one week. The propellant was a double base composition, thermally more sensitive than those considered here; the mechanical properties were altered but no fire or ignition resulted. A railroad hand cart bearing a Polaris ran past the stops at the end of the tracks, the motor slid several inches. There is no record as to whether the engine was fired but certainly there were no immediate serious consequences[7].

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*The latter point is moot: the author knows the answer (or thinks he does) before he asks the question. However, any information a reader may have would be of immense help in completing the recorded history.

One witness, who refuses to be identified, claims to have been present and to have seen a crane drop a Polaris from an indeterminate height into the tube of a Polaris submarine. The latter, of course, was severely damaged. There does not seem to be a record of the disposition made of the missile. There were no immediate consequences other than physical damage to both units.

The gantries on which complete assemblies are moved have never collapsed or been toppled. They have, however, been derailed [10].

Despite many rumors to the contrary and the expectations of many, there do not appear to be any reported instances of bullet holes or marks on the units containing any rockets at the time of inspection at Cape Canaveral [10].

Many years ago there seems to have been an accident in England, involving explosives, which bears upon the present problem. Either due to malfunction or faulty procedures, the tires of a truck in motion rubbed against the container and overheated it. Explosion of the contents occurred [9].

During one Polaris flight test at Cape Canaveral the first stage malfunctioned and ignited the second stage which contained conventional propellant. The latter rose 300 feet, turned around and headed for the ground while burning at both ends. Though many fires were set and broken pieces of propellant continued to burn, there was no explosion [7].

The "Abortive Missile Reports" are classified Secret and are, therefore, unsuitable for inclusion in this paper. A few significant facts can be drawn from them and, without violating security regulations, reported here.

(a) One solid propellant system impacted in the launch area. Though there were many fires, there was only a very mild overpressure and no significant damage.

(b) A large solid motor fell into the ocean after attaining an altitude of three miles. No propellant was aboard at time of impact, but - if it had fallen on land - there would have been many fragments from the case.

(c) The first stage of a two-stage solid propellant motor was deliberately ignited. A malfunction in the command system ignited the second stage which rose to an altitude of one-quarter mile where it was destroyed with 3 tons of propellant aboard. Meanwhile, the first stage burned on the pad. Only fire damage was reported.

(d) Another solid propellant motor gave difficulty which caused it to impact with 3 tons of propellant aboard. The resultant explosion left a crater 8 ft. deep x 15 ft. across. No other damage was reported.

There are other reports involving solid systems. In general, though there may be localized explosions reported,there do not seem to have been any major blast effects. Rather, easily controlled fires and some fragmentation of metal parts seem to be the rule.

Liquid systems, too, have malfunctioned. Mostly these are LOX/RP-1 engines. Many fires and some blast effects have been reported. In one instance peak overpressures as high as about 1 psi have been reported at distances of 500 ft.

So it is seen that many predictions have been verified. Missiles have been damaged in transit. They have been dropped, jarred, and shaken. They have been overheated and overcooled. They have ignited prematurely (but no command) and have impacted at the launch area.

They do not seem to have been the target of small arms fire, nor is there any evidence of their having been struck by lightning. There is no experience to indicate the premature activation of any ignition or explosive component except as the result of a faulty command. Squibs and detonators have, so far, behaved as intended [8]. There is no assurance that this record can be maintained. In fact, the experience of the industry is such that we must anticipate that, sooner or later, an incident of this type will occur. There are 600 electric storms per year in the vicinity of Cape Canaveral.

In summarizing our analysis of the types of accidents to be expected and of those which have occurred, we return to an earlier statement: "If it can happen, it will happen."

IV Systematic Approach to Hazard Classification

On the basis of the preceding it has been established that:

1. Large solid propellant systems present a significant potential hazard.

2. Almost every type of conceivable accident has occurred. Of those which have not, it cannot be assured that they will not.

However desirable it may be, analysis of experience is not sufficient for hazard classification; a more systematic and complete approach is needed. It has been the policy of the explosives industry to anticipate and prepare for the worst possible disasters by simulating the conditions under which these might occur. Test results then act as a guide to the establishment of safety precautions. This is a conservative approach suffering from one weakness: no account is taken of the probability of a particular type of accident. On the other hand there is a significant virtue in this approach: often tests under the worst possible conditions indicate the maximum hazard to be much less than anticipated. The value of this approach will be demonstrated in the following sections.

Following this conservative philosophy a number of different types of tests have been run. These fall into the following categories:

impact

bullet

sled

large-scale drop

bonfire

small scale detonability (gap test)

large scale detonability (Beauregard test)

thermal stability

Some of these, such as the bullet test, reproduce almost exactly a potential accident. Some, for example the sled tests, are attempts to simulate an accident. And some, e.g., the impact test, do not relate

to any real situation. A brief discussion of each, with results, will be presented. An effort will be made to interpret the results in terms of their applicability to the situations discussed earlier.

A. Impact tests

The procedure for tests of this sort is well known, and the results have been presented elsewhere[10,11]. The most obvious interpretation would be that conventional composite propellants are more sensitive to shock than booster explosives. Now this simply is not so, and current thinking relates impact testing to ignitability rather than to shock sensitivity.

Thus the lesson of impact testing is that propellants seem to require less energy than explosives for ignition. Accordingly missile handling techniques must be devised so as to provide the maximum precautions against premature ignition. The situation to which this particularly applies is that in which the units of a segmented system are being assembled. Ignition of the propellant could easily result from "tramp" propellant remaining at the joint. Depending upon the state of assembly this could make the rocket propulsive and, in any event, would certainly result in a very serious, probably uncontrollable, fire until all the propellant was consumed. Since, however, this would be less severe ignition than normal, the system would not be expected to misbehave in any other way provided it could be restrained during the combustion period. Even if nonpropulsive it should not be permitted to fall because this could make the grain crack and might lead to a pressure-type failure of the case and consequent spread of the burning propellant.

B. Bullet sensitivity

Included in this type of test is any in which a high velocity metal fragment strikes a propellant sample or its container.

Results at Aerojet General demonstrate that the propellants under consideration here are "relatively insensitive to bullet impact." A .30-calibre armor-piercing bullet having an impact velocity of about 800-1000 ft/sec at impact is required for ignition[13]

Personnel at the Naval Ordnance Laboratory report [9, 14, 31] that sharp-nosed bullets which penetrate the motor case may cause the motor to ignite, but with conventional propellants nothing worse. The theory here is that the bullet creates a region of high temperature about its own path and only combustion results. Even with blunt-nosed bullets, using conventional propellants, only ignition results.

C. Sled tests

A most interesting series of tests was run to establish the hazard classification of the double base 3rd stage of Minuteman. Cal. 50 armour piercing bullets were fired into the motor from a distance of 100 ft. and with a velocity of 2800 ft/sec. The motor ignited and developed full pressure and thrust 0.9 second after impact. Four seconds later the case ruptured. Even with this detonable system only burning ensued. Solid propellant motors have been placed aboard rocket sleds aimed at concrete walls. Striking with a velocity of 1000 ft/sec (680/mph) it has been calculated that this generates a shock of the order of 14 kilobars [14]. Tests such as these occasionally cause ignition; even with double-base detonable propellants detonations are unkown (one sensitive type of double base explodes only when using a terminal velocity of approximately 3500 ft/sec = 2380 mph.

D. Large scale drop tests

A standard test involves filling either a thin-walled motor or a standard bomb with the propellant in question and then dropping it from a height of 40 ft. to generate a 1 kilobar shock in the propellant. Tests are run in which the drop is upon flat steel, a corrugated surface made from angle irons, or a surface from which large steel studs project for several inches. In general, if and only if, the case is pierced by the drop, ignition results [33]. Even with double-base propellants no explosions have resulted [15].

E. Bonfire tests

These tests originate from a desire to simulate what happens when a wooden box-car containing explosives burns. In general, composite propellant motors subjected to this ordeal ignite, probably at the liner interface. The only consequence seems to be a mild pressure

rupture with some flying pieces of burning propellant [9, 14]. This was the experience when a first stage Minuteman motor was tested [16, 17], and also for a third stage Minuteman [32] - when the second stage was similarly tested there was no case rupture [17]. No similar tests have been run on Polaris, nor are there any scheduled [7].

F. Small scale detonability tests

These tests have been well described [12, 18], and of all sensitivity tests, are believed to be on the firmest scientific footing. From these tests it has been quantitatively established that most double-base propellants, though detonable, are distinctly less sensitive than many of the least sensitive military explosives. It has been confirmed that the composites of the type considered here are nondetonable at and below diameters of the order of 2 inches. On the other hand, it has also been established that the same composite propellants in a porous state become highly sensitive to shock and are detonated with an ease comparable to that of the energetic double-base formulations.

G. Large scale detonability (Beauregard) tests

There is as yet no adequate theory which predicts the critical diameter of an explosive system. In an effort to determine the detonability of Polaris, using composite propellants, a series of tests, code named Beauregard, was performed during the summer and autumn of 1958 at the Naval Ordnance Test Station [19]. They established that the critical diameter for detonation of the solid nondefective composite propellant was above 20 inches. On the other hand considerable blast effect, attributable to the propellant, was recorded indicating that, in the presence of a severe shock, a significant quantity of the propellant reacted rapidly enough to contribute to the peak overpressure.

A detonation sensitivity test of a Minuteman second stage engine was conducted [20]. The purpose was to determine if the engine would detonate when subjected to the detonation of a 100-lb shaped charge of composition B placed on the external surface of the chamber wall (not the head end). The explosion subsequent to initiation destroyed all recording equipment which was located within a barricaded region approximately 250 feet from the charge.

Detonation sensitivity tests have been performed on full scale MInuteman first and second stages[17] using various test geometries. As with the Beauregard tests, though no detonation of the propellant was detected, significant blast effects were noted. It is not possible to scale these results to apply to larger systems.

H. Thermal stability tests

For a number of years a standard test, described elsewhere [10,21], has been used. It is often run by dropping a sample of propellant into a hot bath and determining the time to explosion. Of questionable theoretical value, it has the advantage of being, like the impact test, a simple one to perform and one which permits the ranking of various formulations according to their thermal sensitivity in a particular situation. Recently, more refined techniques have become available [6,22]. These give considerable promise of being more generally applicable. The theory permits predictions, from the experimental results, of the temperature above which a sample of known size cannot be stored with safety. Although it has not yet been satisfactorily demonstrated that the results apply to large rocket motors there are promising indications that this might be accomplished[23] and improved methods are being developed to cope with geometries other than the simple ones to which the present treatment is restricted, i.e., cylinder, slab, or sphere[24]. We still need,however, a conclusive demonstration that the kinetic assumptions are valid and that the low-temperature energy of activation which these experiments determine is applicable to higher, predetonative temperatures. At any rate, the present information[6,23] is sufficient to show that no safety hazard is presented by the storage of any conventional composite at any reasonable ambient temperature. This, notably, does not include degrading processes which may occur at extremes of temperature and which may be cause for rejection of a motor. On the other hand, high energy double-base materials are much more sensitive[6] to moderate temperature excursions. Multiple stage rockets, of which one stage is such a sensitive material, should be protected from excessive heat. There are, so far, insufficient data to permit the establishment of general criteria for storage of energetic propellants.

V Significance of Testing - Hazard Classification Accomplished

How do these tests relate to the actual hazards of missile handling? Consideration of the many types of mishaps which have occurred or which reasonably might happen leads to the conclusion that to each type of mishap, regardless of the operation during which it might occur, there correspond one or more tests of the types already described. The proper hazard classification depends upon the proper interpretation of the existing tests. (For some situations, additional testing might be desired.) In the following table we have attempted to analyze the previous discussions by correlating hazard or mishap with the pertinent test.

TABLE I

*Depends upon modification	Shipment	Trans-and Site	Assembly Checkout Storage	Ac-Launch	Post Launch	Impact	Bullet	Rocket Sled	Large Scale Drop	Gap	Beauregard	Thermal Stability	Miscl.
Wench failure	x	x		x				x	x				
Inproper Loading on Transporter	x	x						x	x				
Jolting-"bumping" vibration	x	x		x				x	x				Vibr ıtion
Small arms Fire	x						x						
Train, hiway, other accidents	x	x						x	x			x	
Failure of thermostat	x	x	x									x	
Proximity of other accidents	x	x	x	x			x	x	x	x	x	x	
Seaborne or airborne accidents	x	x						x	x			x	
Tramp propellant caught at joint			x			x							
Large masses brought together			x	x	x						x	x	
Ordnance malfunction			x	x	x			x	x	x		x	Sub-assembly testing
Premature ignition			x	x	x			x	x	x		x	" " "
Modification of mtr.			x	x				*|					
A large mtr. topples			x	x				x	x				
Explosion of liquid stages				x	x		x					x	Effect upon ord. items
Lightning & electro magnetic radiation				x								x	" " " "
Ignition malfunction					x					x			
Guidance malfunction					x			x	x				
Burning of defective grain					x					x	x		
Activation of destruction system					x					x	x		

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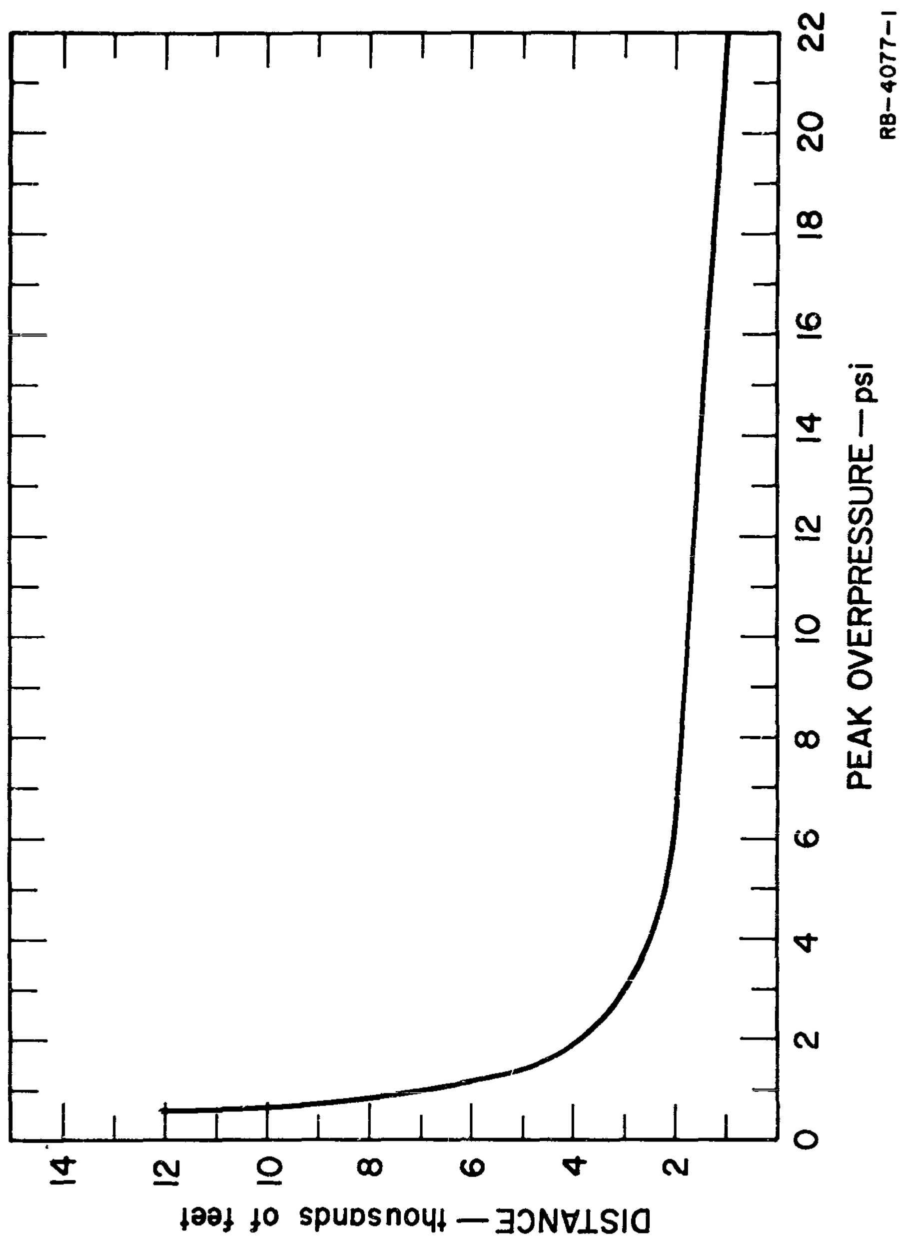
PEAK OVERPRESSURE — psi
0 2 4 6 8 10 12 14 16 18 20 22
DISTANCE — thousands of feet
2 4 6 8 10 12 14
RB-4077-1

It is seen that the approximately (and somewhat arbitrary) forty different combinations of malfunctions can be evaluated, with few exceptions, by one or more of seven types of tests.

Immediately it is seen that, with one exception, all of the anticipated situations which may occur during shipment or on-site transportation are comparable to bullet, rocket sled, large scale drop or thermal stability tests. The exception involves the relation between the "proximity to other accidents" and the shock sensitivity type test (gap or Beauregard). Later it will be shown that no explosion originating from beyond the rocket can generate a shock strong enough to do anything but ignite the grain. The results of all other tests indicate that the worst possible consequences of an accident during transportation would be a severe fire. Individual segments open on both ends would merely burn.

A monolithic rocket could explode (pressure vessel type failure) or become propulsive. Insofar as existing shock sensitivity tests indicate, neither system is detonable. Accordingly, segments may be transported as Class B explosives (Ref. 25, p. 45) monolithic rockets must be transported as class A explosives (Ref. 25, p. 37).

During assembly, checkout, and storage, all of the tests are relevant. Again except for the shock sensitivity tests, all existing data and test results indicate that no conceivable accident could cause any but a fire hazard. If the segments have been assembled or if the system is of the monolithic type a propulsive condition or a pressure vessel failure may result. It is now the the practice at Cape Canaveral to use large physical barriers to prevent a propulsive system from "launching" itself [8]. If this procedure is adopted for larger systems, such as those envisioned for NASA missions, we see no reason for classifying them as anything but Class II. The results of the shock sensitivity tests indicate that, even if the propellant is nondetonable, the propellants are capable of contributing to the shock from a nearby detonation. The extent of this contribution cannot be forecast at the present time. If conventional propellants are to be used in conjunction with double base or other class IX formulations it might seem that the

entire system should be so classified. This seems to the writer an overly conservative approach; however, more work is needed to develop the necessary scaling laws. The likelihood of this combination being used is, at present, slim; accordingly it is best to delay consideration of the problem until it is germane. There may be concern because of the presence of a quantity of explosive units or systems aboard the rocket. Most of these are in the form of explosive bolts or actuators or conventional linear or shaped charges for destruct systems. These are designed for a specific function which normallin involves, locally, a relatively small explosive effect (the total amount of explosive present is not the criterion). At worst they will rupture or perforate the motor case to make it non-propulsive. They may also shatter a small quantity of and ignite the propellant. The result again is fire; neither propulsion nor detonation is a consequence. A pressure rupture is a possibility.

What about the modifications which can be done on the motor? Current regulations at the Pacific Missile Range[26] permit neither redesign, nor modifications, nor changes of any element of ordnance, including the propellant system on the base. Such work must be done by the manufacturer at a facility, other than PMR, of his choice. The decision as to when removal of the unit is required is made by the Range Safety Officer, not by the manufacturer or his representative. At Cape Canaveral similar restrictions apply[8]. Mechanical repairs can be made. For repairs of a nature which expose the propellant, the system is moved to a specially secured area. For significant grain or ordnance repairs, the unit is returned to the manufacturer. The decision is made by the Range Safety Officer. So long as this policy is rigorously pursued we see no significant additional risk. We are particularly in favor of having the manufacturer divorced from the decision. Range Safety personnel, if they err, will err on the side of caution.

The problem of "tramp" propellant at the surface where segment juncture is to be accomplished has been dealt with in the section dealing with impact testing.

In summary, during the assembly, checkout, and storage periods, provided a propulsive system can be restrained, conventional systems should be stored as Class II explosives, presenting serious fire and some pressure vessel (with fragmentation) hazards.

During the pre-launch period much of the foregoing applies. A review of the discussion on possible hazards during this period indicates the existence of several paths for activation of ordnance units. For this reason it has been the practice to install squibs, igniters, and detonators as late in the countdown as possible, perhaps as little as 75 minutes before launch. Subsequent to this time stray E. M. F's may activate destruct or ignition systems (or both) or perhaps separate stages prematurely. Destruct system activation renders the system nonpropulsive but starts fires and may climax with pressure type burst. Ignition renders the unit propulsive and stage separation may, in the extreme of a filled liquid oxygen - fuel system cause a serious explosion. More will be said about this last possibility. Premature ignition with resultant propulsion can be handled promptly by deliberate destruction. Hence except for the possibility of nearby explosion, the system again can be treated as a Class II fire hazard with some possibility of fragments; for the post-launch period, explosion on the pad is possible. For a propulsive rocket returning too soon, with a liquid stage aboard, to strike at on near the launch site, explosion is probable. (The impacting of a burning grain is not the same as the superficially comparable rocket or drop tests on unignited burns). In either case there is insufficient information upon which to base a hazard classification. Certainly the rocket presents a real explosion hazard and cannot be considered Class II; on the other hand, if it is assumed to be nondetonable neither is it Class IX or X.

Except for a deliberate vagueness concerning the detonability, it has been established by the foregoing that the large conventional solid propellants destined for NASA missions offer only fire, pressure rupture, and associated fragment hazards. They can, as segments, be shipped as Class B explosives; otherwise they may be treated as Class II.

What about the detonability? This is dealt with at length in the next section. However, to complete the list of recommendations for proper hazard classification the conclusions will be presented here. Until the igniter, completely assembled, is installed, or until the upper stages are being filled with the liquid fuel and oxidizer, the solid grain can be considered as Class II. However, once either or both of these steps have been taken, the entire system must be considered as Class X and a new larger security area defined around the launch pad. This conclusion is independent of whether the propellant is, itself, capable of sustaining a stable detonation. This act imposes a severe handicap upon the facility, but it is one of relatively short duration and can probably be tolerated.

VI Detonability of Conventional Solid Propellants - Is it Important

It is now necessary to evaluate the importance of the detonability of the propellant under consideration. Lest it be minunderstood, as often happens, we use the term "detonation" in its completely rigorous meaning: a chemically supported shock wave, of stable velocity, propagating with a velocity which is supersonic with respect to the unreacted medium.

Small scale gap tests confirm merely that conventional composites will not detonate in diameters of the order of 2 inches. The Beauregard tests confirm that the critical diameter is greater than 20 inches. Boyer[27] at Aeronutronic has made a preliminary prediction that these materials will not detonate at any diameter. On the other hand, Anderson[28] at Aerojet feels that the critical diameter is of the order of 40 to 60 inches. We avoid dwelling further to evaluate the merits of these postulate by noting that it is premature to test either; the experiments would be inordinately expensive and, as will be seen, the results are not necessary to this program. To test these theories it would be necessary to prepare several, probably four, propellant samples each of the diameter to be tested and of length at least six times the diameter. (The Beauregard tests suggest that for diameters greater than 20 inches a length to diameter ratio of 4 is inadequate). Assume the diameter to be tested is 60 inches this is very close to the web thickness of the 3.7×10^6 lb. motor mentioned earlier. The length would have to be 360 inches, the volume would be 655 cu. ft. and the propellant would weight approximately 65,500 lbs. At \$1.50 per pound, four such samples would cost about \$400,000. The

explosive boosters might cost half as much. Thus, over $600,000 would be required merely to buy the raw materials. Over and above this are the costs of hardware, transportation, instrumentation and of designing the test and arranging for the necessary personnel to supervise the operation and analyze the results. Obviously this would be a multimillion dollar undertaking.

Let us assume the tests are run and show that the propellant is detonable in 60 inches diameter. There is still no indication as to how great a shock is required for initiation. The additional testing required to obtain this information could easily treble or quadruple the cost. If we forego the additional testing, we can make the reasonable, assumption that the propellant is about as sensitive as some of the composite propellants with high energy binders. These latter require shock pressures of the order of 60 kilobars for initiation[12]. Explosives sensitivity research teaches that in order to detonate an explosive the requisite shock pressure must be applied to the acceptor (in this case the propellant) over an area approximately equal to $(\pi \frac{d}{2})^2$ where d is the critical diameter. Thus, even if the propellant is detonable, its detonation, even as a thought problem requires that we provide an approximately 60 kilobar shock wave over a circular surface having a 60 inch diameter. For larger critical diameters the problem is proportionately larger, of course. Only a nearby detonating explosive charge of 60 inch diameter or greater could generate such a shock. The closest thing to it may be the liquid stage above the solid. Estimates have been made of the shock pressure in a liquid hydrogen-liquid oxygen detonation; it is reported[29] that this may be as high as 45-50 kilobar. For the gases it will obviously be lower. Even worse, the LOX/RP-1 system may generate pressures[23] as high as 140-150 kilobar. When one allows for a reasonable interstage separation distaned, plus the interviening hardware to attenuate the shock it is unlikely that an initiating shock will reach the solid propellant. Thus the one mechanism by which a shock-initiated detonation becomes even theoretically possible requires a precursor detonation of the liquid second stage. Although the possibility of a transition from burning to detonation

must be considered it has been demonstrated, even for the sensitive double base systems, that pressure rupture of the motor cases occurs rapidly enough to preclude such an incident.

On the other hand, the history of gap testing demonstrates that cracked or granular systems either detonate (stably) or contribute a large amount of energy to the explosive shock wave. Even if the propellant is nondetonable, the occurrence of the postulated second stage detonations would undoubtedly initiate a fracture process which would furnish the medium for the explosive reaction. Our ability to predict the magnitude of the explosion is inadequate. Much depends upon the source and location of the fracturing pulse. If it is external to the grain and at the head end damage might not exceed that resulting from a 20-30% TNT equivalent for the first stage [17]. Undoubtedly the nature of the motor would have a strong influence. A crack might propagate easily through a monolithic grain. It is hard to see how it would propagate beyond the first segment of a multi=segment motor. An internally generated (as from ignition) shock might be sufficiently severe to shatter a very large percentage of the propellant-segmented or otherwise. If the source was on the external wall medway between the ends, as with the Minuteman test[20], a great contribution[7] might also result. Unfortunately, we can conceive of no way to simulate these tests on a small scale - we simply do not know enough about fracture mechanics. Adequate testing would have to be of a statistical nature, many tests would be required, full scale motors with complete upper stages would be required and, to this writer at least, the cost would be horrendous exceeding probably by one or more orders of magnitude the high cost of the relatively simple detonability test. We cannot recommend such a course of action. Rather, as previously indicated we recommend the alternate approach: for the limited period during which the ignitre is armed and the upper stages are fueled the entire system should be classified as Class X and the necessary precautions taken.

VII Summary

Evidence has been accumulated and is presented in such a way as to justify the following hazard classification for the large (conventional) solid propellant motors envisioned for NASA space missions.

While being transported, motor segments may be considered Class B, monolithic motors must be Class A. During storage, check-out and assembly both types may be handled as Class II. They may also be Class II on the launch pad, prior to ariming of the igniter or fueling of the liquid stages from that time on, they must be considered as Class X.

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15. Mr. L. Ullian, Patrick AFB, Florida

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(32) Summary Report: Engine Hazard Evoluation Tests - Hercules Powder Co., Magna, Utah - Report MT1-271 dated 29 July 1960 (Confidential)

(33) Altman, F. D. "Drop Tests of Ammonium Perchlorate Propellant Charge" - Naval Proving Ground Rept. No. 1601, dated 23 May 1958 (Confidential)

Dr. Price: I just wanted to ask - in the consideration of various tests, whether you gave any particular attention to one that was not listed there as such and that is, friction, which I admit would eventually go a question of hot-spot formation. But I'm asking this because it has become fairly recently evident that there is a very severe problem of initiation of large charges by a certain type of sliding friction.

Dr. Amster: This is discussed in the report. Friction came under the type, for arbitrary classification, thermal stability.

Dr. Price: Right, this has a very close connection, that's why I asked if you'd considered it.

Dr. Amster: Thermal stability includes many many things in the report at least being rather arbitrary and friction is considered.

Lt. Rubinstein: My question is an open one to the floor also. In your studies, did you consider electrostatic hazards to solid propellants?

Dr. Amster: Yes, I'd like to make a point by the way. It was brought up before the fact that the Pacific Missile Range apparently has different regulations than the Atlantic Missile Range on static and especially electromagnetic radiation. One thing that I think bears nothing is that while electric storms are, I believe, exceedingly infrequent at Point Mugu and Point Arguello, they have about 600 a year at Cape Canaveral and this certainly puts a different light on their problem.

Lt. Rubinstein: Was it considered from the standpoint of electrostatic body charges? What I'm getting at is the need of utilizing non-sparking tools when working with solid propellants and the reason I say this is an open question to the floor, is I'd like to know if there is any work being done at the present time by any of the agencies represented here today. There seems to be a lot of misconceptions in this field too and I think there is a lot of money being spent needlessly on non-sparking tools which cost quite a lot more than normal tools and people don't know what they're dealing with. We get into elec-stat and things like that when we're not dealing with exposed propellants.

Dr. Amster: Let me answer your question by saying that in detail we did not consider body sparking and the reason is the following. This bears on the philosophy behind the entire paper. We assumed that the systems will be exposed to sparks at some time or another without regard to probability and the question arises, if there is a static discharge, what can happen. Having established that we do have a static discharge, we're no longer concerned with the purposes of the survey and no longer concerned with the likelihood or the source.

Mr. Taiani: With the permission of the speaker, I'd like to have one point deleted from the record and that's the point about the propellant when you have it on the pad and you're fueling an upper stage or something of this sort and it's Class 10. I think that this is unfounded at the present time and I'm a proponent of trying to get a working group together to determine what these hazards are because of expenses involved in liquid-solid combinations. The reason I say this is some people take the minutes of this meeting and use them as the gospel and so at times we're confronted with trying to disprove these items.

Dr. Amster: You do not have the permission of the speaker, you just put the fat in the fire and maybe this is as good a reason as any to cut the talk short. Working within a framework where we have only Class 2 or Class 9 or Class 10 and nothing else - and this is unfortunate - I'm afraid there is no alternative. If there is any possibility of an explosion hazard, and there certainly is in such a situation - if there is any possibility of an explosion hazard, we have no alternative but to classify it as Class 10. Now, I agree with you that there should be a better classification because once you've classified it as Class 10, as I understand it, you then have imposed upon you certain distance safety requirements which essentially are based upon the assumption of more or less a so-called 100% TNT equivalent. This, I agree with you, is unfortunate and it's this kind of large scale test that I made reference to - whether we perform them or not is something that should be discussed by the people who are paying the bills and are concerned with schedules and so on. It is not a scientific kind of discussion. However, in order to establish what the real explosive hazard of this thing is we're going to have to perform certain tests. These tests will have to simulate what can happen and until we perform these tests, I think we're stuck with a Class 10 designation.

Mr. Taiani: I don't see how you can do this. If your previous test alone is a Class 2 item and you run the test according to either the ICC or the DOD Directive and it's a Class 2, I don't see how you can put it in a Class 10 because you're putting a liquid on top of it. I grant you it might be liquid hydrogen.

Dr. Amster: That's exactly what I have in mind.

Mr. Taiani: We're getting into all kinds of trouble on this because of this type of statement that is being made today without any back-up of information.

Dr. Amster: Let me try and give you some back-up information.

Mr. Taiani: There are other people that evidently want to speak on this same subject. I won't say any more.

Dr. Amster: You've said enough.

Dr. Zernow: I'd like to go on record as being in violent disagreement with the speaker on the subject of the importance of critical diameter experiments and I'd like to make the point that if one spends a great deal of money on full-scale tests, that without using the concept of critical diameter and it's extension to the concept of critical geometry, that you'll be spending a great deal of money, you're not extracting the information that is possible to get from a large scale experiment.

Dr. Amster: These detonability type tests - let's suppose we have established that the critical diameter of 120" grains is 110". We then have to find out on the pad how we're going to initiate this thing. If we have established that we're now dealing with a system that's above it's critical diameter for detonation, I don't think the fellow on the pad is really concerned basically with whether it's detonable, but whether under the circumstances to which this thing is exposed, can it be made to detonate. However, since almost anything that you can postulate which can make this thing detonate is going to cause a heck of a big explosion anyway - I think as far as the fellow on the pad is concerned, it's pretty academic.

Dr. Zernow: In running such a large experiment then, what initiation system would you recommend?

Dr. Amster: First of all, don't misunderstand what I'm about to say - I'm not recommending that we run these tests. I want to make this clear.

Dr. Zernow: It wasn't clear.

Dr. Amster: I just wanted everyone to understand it. I'm not recommending that we run these tests. I'm saying that if we must answer this question, then certain tests are necessary - please don't misunderstand that. I would say that the tests that ought to be run, for example, a system with a second stage of hydrogen-oxygen is to try and imagine the worst that can happen with the hydrogen-oxygen donor and expose the solid system to the impulse or to the shock from this donor. Because worse than this you can't imagine and if this shock happens to be for example, less than the shock necessary to initiate detonation in the propellant, you've solved your problem, even if it's detonable.

Dr. Zernow: I'd like to make the point that given any arbitrary initiation system in which I mean the initiation system as defined in terms of the shock amplitude and its duration and all the appropriate parameters and given an understanding of how critical diameter transforms itself into critical geometry you have there an essentially straight forward although very difficult basis for making your computation, not only as to whether the stuff will initiate but how much of it will be consumed and when the detonation will die out of the system and I really think that this is the only hope because it has the possibility of being able to be put on a computing machine for resolution

so that one can run these very expensive experiments on a much more satisfactorily economic basis.

Dr. Amster: If you're talking now about imposing a shock upon a propellant, it's propagating partially and dying out, I agree, this is the kind of research that ought to be supported, I think fracture mechanics for example which bears upon the problem. Some other things, yes, but as far as critical diameter as such is concerned, although it's certainly an interesting problem, as relates to the problem on the pad, I can't go along with you. I just disagree.

Mr. Wood: I represent the programming side of the missile system or vehicle system. It's very refreshing to hear that there's somebody interested in testing a solid greater than 2" in diameter. I have to take issue with the gentleman over here that wanted to take this item out of the minutes. It just so happens that I am associated with the Program 624A vehicle of the Titan III and we are at this moment listed as a Class 10 item on the pad at AMR. It's not something that's coming up in the future, it's something that we have been told we are listed with today. So let's not try to forget it, let's not put it out of the minutes and think that this problem is going to go away. I think we should spend a little more time and pay attention to these problems. I would like to agree with Dr. Amster that we could do away with detonability tests, however, I am saddled with this problem also at the Cape since the main issues seem to be, will this beast detonate if it falls over or will it detonate if it's initiated by some unimaginable or unknown or unspecified donor. I get pretty worked up about this situation because I think we have a question with respect to the Titan III program that's almost unanswerable. I would like to have some discussion regarding, what do we realistically do for minimum test criteria associated with a vehicle of 10 ft. diameter. Awhile ago I asked Mr. Herman about the new minimum test criteria. Since then I've been informed that the new minimum test criteria is exactly the same minimum test criteria I have in my possession now which says 8" is all that's necessary to test for a critical diameter. Yet I've got a vehicle which is 10 ft. in diameter. What do I do with it?

Mr. Walther: I was talking with Mr. Herman and I think a number of the people that have been working on the explosive quantity-distance committee and I think we all agree that there's going to have to be a great deal of unification on the discussions on the classification of propellants as well as the establishment of quantity-distances. For example, you cannot logically classify a propellant as a Class 2 propellant and consider it as a fire hazard and then put it on the pad and subject it to a donor and say we have a percentage of yield and call it the same propellant. We're going to have to get some correlation as far as the group classifications are concerned. Of course as far as the Class 10 is concerned, on the pad for a particular vehicle, this has been an arbitrary range decision and of course there ar other range decisions

which are arbitrary other than the 1 amp 1 watt. However, these people have specific problems, they have safety problems to consider, and I think that rather than criticize, of course, this is not criticism, I think it's going to behoove a group such as this and the agencies to assist in getting information to give them some realistic ground rules in order to establish the classification. However, I might point out and this is concurred in by range safety, that if we do have a solid propellant and we go on the pad as a Class 10 vehicle, this does not change the yield or the classification of the solid propellant. So we still have the same quantity-distance.

Mr. Weintraub: I have one comment to make to Mr. Wood and that was there was a high hazard stand and still is established at Edwards which has been doing quite a bit of testing when I was with STL several years back and we did run tests on full scale third stage, as a matter of fact I also ran susceptibility tests as you're probably aware of. In addition to that, sympathetic detonation tests to see what would happen when we stored several of these engines together, etc. I think that Dr. Amster can also tell you about tests that he's run on large size grains. This has been done, so I think that what we're doing now is just looking for a larger size grain, but this has been done, we've gone over 2".

Maj. Eberle: Mr. Wood is working on the same problem that our shop is and seeing that we're beating around the bush, we have on board now a solid manufacturer that is making for the Air Force a 120" booster. The Range has told us, both Ranges, we are Class 10 until we prove otherwise. We told the Range "we'd be glad to prove it, we've got the money, what do you want us to do." They said "I don't know, you figure it out, you're the Project Officer." So we go to Mr. Herman and he says "I don't know, you give us a recommendation and we'll work with you" and this is all he can do. We talked to Dr. Amster, to these other people, and we say we now are the project that is going to push this thing, my job is to get this thing tested. If anybody in this shop, and assume after we get program go-ahead which is imminent, we'll have the money, we can buy from the UTC the motor segment, for Pete's sake, let's get somebody together in this room and tell us what to test. We must have the thing tested. Further than that, other than the fact that we are Class 10 and all the people we've talked to don't seem to think this is a reasonable test, we are restricted until we prove it to be Class 10. We have a room reserved in this building at 1330 to hassle this thing out, we've talked to several people here asking them to talk to us about it. We have in our hands a letter from the various ranges and other interested people that says if we can get a group of people together, experts, and some have said they aren't interested in it, but if we can get these people together to devise a test plan, then we will take this plan, buy some motors, blow up the silly things and settle this thing. I don't know what better opportunity you scientists in this room would have than an opportunity to test your

theories. Let's get with me at 1330 back here and work this thing out. We'll be getting together with a few others of you whom we haven't had a chance to talk to and see if we can't arrange a meeting on the West Coast at Aerospace which company is working on this for us, and work this thing out. Are there any questions on what we have in mind. The Ranges have said that if this so-called AdHoc committee can devise a test program, that they then will not add any additional restrictions to us on the range, that if this committee proposes a test plan, they're not agreeing to the results, only the plan, then we can let the results fall one way or the other. If we're Class 10, we don't care really as a program office, we'll go Class 10, we'll have to buy the extra operational items, etc. and operate that way, but right now we're restricted and we don't believe we necessarily need to be. So, we'll get with you people and I invite you to this back room afterwhile.

Dr. Amster: You say this is the time for all us scientists to come in and test our theories. I think the real problem is that we don't have a theory and what we're doing is exactly what I bemoaned before, we're making roast pig by burning down the building and regardless of whether we agree now, the kind of hassle we're having here is exactly the kind of thing that has to be resolved, so that when it is resolved by whatever procedure is utilized, we can solve not only your problem but the next guy that comes up with a 240" motor, because we know these things are going to come along. We want to be able to stop once and for all this indiscriminate blowing up of literally millions of dollars of Uncle Sam's money to find out what is going to happen to a missile which certainly isn't going to be with us for very long, as progress is made. And this is one thing we've got to do, first of all we need some research in these things, aimed at avoiding these tests, not supporting them, forgive me. Secondly, as far as the Explosives Safety Board is concerned - I don't know whether or not what I'm saying is true, but I'm going to make a guess, they have now come up with a set of tests which essentially were dictated to them. How do we classify something as Class 2, how do we classify it as 9 and how do we classify it as 10. You have a problem which is neither Class 2 nor Class 10. We need another classification. Either that or we need some kind of a subparagraph under Class 10 that says we don't have to consider 100% TNT equivalents, we can use a different kind of a quantity-distance table. So we need the theoretical work, we need experimental laboratory type work and we need a new classification.

Maj. Eberle: Apparently, this is the time to do just that. If the classification is wrong, it seems to me now, that with this program which is the first program of the large 10 ft. diameter beast, it seems to me this might be the time to work out this thing you're asking, but we have to start someplace and we are committed to test this thing because Col. Blamar told General Davis at the Range that we would test it. However, this can be changed, maybe, but the point is that the burden is now on us to recommend something for the future and this is just the beginning of the large solids and this is what we're asking for.

Dr. Amster: Let me point out that the only better time to start research than now was yesterday. Let's not put it off.

Maj. Eberle: Right, so at 1330 we can have our little get-together.

Mr. Plouff: Getting back to the old conflict on spark-proof tools, the Navy Department is making a research on the application of spark-proof tools thru the medium of the Naval Research Laboratory. I just wanted to help that fellow that had that problem in hand.

Dr. Amster: If you have that information from NRL, there are some gentlemen at Hill AFB that are very much concerned with this problem of using spark-proof tools. I think it's a case where the left hand isn't letting the right hand know what's going on. You might contact them.

Mr. Jezek: Before going to this meeting, I would like to say something from a safety man's point of view on this Class 2 vs Class 10. I agree that motors should be tested to find out whether they will ignite and burn and be propelled out into space but if you send any site criteria into our office, we're not going to classify it as Class 2, but we'll say use Class 10 distances for this reason. Today you tell me you have a 120" motor, it's Class 2, but next week you may have a 10 ft. motor and it'll be a little different in classification, so if you're smart, gentlemen, you'll get the real estate now, because it's much easier to reduce distances rather than increase them.

Mr. Couch: I've sat here and listened about as long as I can without saying anything. We'll gladly furnish the segments that you want to test. But I think the main question and the first question that has to be resolved is what do you want to know, what are you trying to find out. For example, are you trying to find out whether it's possible under any circumstances to detonate a large grain or whether as Dr. Amster made the point in his discussion, is it possible to detonate it under reasonable conditions and if it is, then what are the reasonable conditions. What are the differences between the reasonable conditions and the conditions necessary to find out whether it is at all possible to detonate. These I think are the type things that need to be resolved before we do anything else. By the way the meeting that is going to take place that Maj. Eberle invited you to will be after our afternoon session and you will need to make the choice between that meeting and the tour. They will be going on concurrently.

Dr. Zernow: I'd like to clarify the misconception about there not being any theories available for these things - there are a heck of a lot of theories available, the trouble with the things is there has been no opportunity to test them. Having an opportunity to test them, one even would have a chance of extrapolating them for some of the sizes that we're interested in, but if we can't even test them at the 30" diameter, how can we expect to say anything about the 120" diameter.

Another point I'd like to make and this is perhaps at the expense of making some people unhappy with me. There is always a tendency for those who face the problem suddenly to decide, boy it would be nice if we had the answers now, yet when several years before the imminence of the problem was very clear and in fact there were many warnings given that this problem would arise and there was very little support for the researchers. And again I think I'd certainly like to underline the fact that there is no better time for starting the research than now and the longer you wait, the worse it will be.

Dr. Amster: I certainly agree with your second point and the first is something we can consider some other time, but to support your second point, Lou, wasn't it around 1955 that George Kistakowsky was at the DDT meeting at NOL and he made essentially the same plea word-for-word that you did - "let's start our research because this problem is going to be with us a long time."

Dr. Zernow: Recommendations that large detonability experiments be carried out were first made about 1956 to my knowledge and they were turned down because the answer as I recall "what do you expect to learn from it."

EXPLOSIVE CLASSIFICATION OF SOLID PROPELLANT MOTORS AT EDWARDS AIR FORCE BASE

by
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The explosive evaluation test program for Solid Propellant Motors was started at Edwards Air Force Base in December 1959. The Boeing Co. was under a contract at that time to conduct the explosive classification tests for the three stages of the Minuteman ICBM. Nine tests were conducted by May 1960, at which time the program was turned over to the Rocket Research Laboratory (formerly the Directorate of Rocket Propulsion). The Laboratory continued the Minuteman tests as well as adding tests on the Genie, Blue Scout and Skybolt propulsion systems. To date, there have been 35 full scale motors tested.

Since all tests have had the destruction of a motor as the primary objective, the distance to which a hazard could exist has been great. Two remote test sites were, therefore, required to conduct the tests. These test areas were located behind Leuhman Ridge on the Edwards AFB reservation.

Test Facilities

The first test area was originally constructed for the Minuteman program. It consisted of three horizontal firing bays and an assembly and control building located in line along a one mile road. Each test bay was capable of restraining and measuring up to 1.5 million pounds of thrust. Two of these bays were medium hazard bays (Figure 1) located approximately 3,000 and 3,300 ft. from the control building, with data acquisition performed in a barricaded instrumentation room located between them. The single high hazard bay was located 5,000 ft. from the control building and originally had its own instrumentation shelter. Unfortunately, this shelter was destroyed during a detonation test and the main instrumentation building was used thereafter.

The instrumentation was multiplexed on standard IRIG FM bands or through a PDM system and recorded on magnetic tape as is common at many facilities. Standard types of instrumentation transducers were used for thrust, pressure, strain and temperature. However, a special system was used for the blast overpressure measurements. Overpressures were recorded as an absolute value with time by Photocon FM type transducers. The transducers were mounted flush in $\frac{1}{4}$" steel knife edge disks, six to ten inches in diameter. They were located on poles in two radials at 100, 200, and 400 feet from the motor and

30° to each side of the aft centerline. The gages were calibrated, in place, prior to and after each test against a standard pressure gage. All six of these transducers measured side-on overpressures. Six redundant Bikini blast gages were used for backup at the same location as the Photocon gages. The only exception was that three gages in one row measured side-on overpressure, while the other three measured face-on overpressure. The Bikini gages used 1-mil aluminum foil in sixteen holes ranging from 0.066" to 3.00" in diameter.

Since this first area was relatively sophisticated and expensive to recondition after a detonation test, a second test area was established. This area was located at a dirt landing strip on the Edwards Flight Test Range. Void of any tie-down facilities, it was used only for detonation tests. The primary data measured was blast overpressure at five different locations from 100 to 500 feet in a 180° arc. Again a redundant system of Photocon and Bikini blast gages was used. The data was recorded at a revetment 900 ft. from the detonation site, while control was exercized from a WW II tank located 3,000 ft. away.

Tests were monitored at both areas by cameras running up to 4,000 frames per second, depending upon the expected duration of the desired test investigation. A 35mm streak camera also was available when required.

These facilities have proven to be more than adequate to conduct a hazard test program. Since tests of a destructive nature are costly from a program standpoint, redundancy has been imperative to avoid loss of any data. This was demonstrated amply on a test where Bikini blast gages obtained the only significant data. This loss of data occurred, fortunately, only once since the area had been designed specifically for hazardous types of tests.

Test Types

The tests were designed originally to yield information regarding the relative effects of motors when subjected to possible stimuli occurring during handling and operation. Since it would have been impossible to subject motors to all stimuli, it was necessary to select those which were considered to be the most encompassing. These were:

1. Detonation
2. Bullet Impact
3. Fire
4. Drop
5. Destruct System

All tests, except for the drop test, have been conducted on both double-base and composite propellant motors. The drop test has been conducted only on a composite propellant motor.

The first four types of tests have been concerned primarily with the detonation potential of the motor. In the case of a negative reaction, the subsequent objective was to observe the ignition and fragmentation characteristics of the propellant. The primary objective of the destruct system tests was the capability to terminate propulsion of the motor, although, blast, fragmentation, and fire were the secondary effects measured.

The tests were very successful in a destructive manner, and considerable data was acquired.

<u>Test Configuration and Results</u>

The test-results may be categorized into three primary areas. The first was the complete detonation of the motor. A large overpressure shock was generated and fragmentation hazards were due to hardware alone. The second category was that of a partial detonation. Only a mild overpressure shock was generated but large quantities of fragments were thrown, consisting primarily of burning propellant. The third and final category was that of a burning motor. Essentially, no overpressure shock existed, and a minimal quantity of fragments was emitted, but, nearby objects were scorched or burned due to the high radiative heat of the burning propellant. The results indicated that double base propellants generally grouped into the first or third category, while composite propellants grouped into the second and third category. The detonation test was the primary factor which separated the propellants into these groups.

The detonation test was conducted by placing high explosive donors directly upon the motor or by sympathetic detonation of another motor (or equivalent charge of TNT) in close proximity. The results have been relatively uniform as shown in Table 1. Double base propellant motors have exhibited a marked sensitivity to detonation shocks and have detonated with as little as $\frac{1}{4}$ pound of C4. This was placed upon the outside of a $\frac{1}{4}$" thick fiberglass case. Furthermore, the detonation of an 18" diameter double base motor weighing 500 pounds, has caused sympathetic detonation of an identical motor located 28" away.

Composite propellants, on the other hand, have exhibited a relative insensitivity to detonation shocks. In over 15 tests, there has been only one motor where the measured equivalent TNT detonation has exceeded 22% of the grain weight. Additional tests were unable to duplicate this detonation. The only postulation which can be offered, is that it was a rejected motor with separations and porosity that could have contributed to an adiabatic heating within the propellant. It is the same effect used to explain the support of a detonation wave in finely divided composite propellants. A missile configuration test with the composite propellant motor attached to a 3,500 pound double base motor indicated only a 22% contribution by the composite propellant

while complete detonation occurred of the double base motor. High speed motion picture coverage dramatically substantiated this with large quantities of burning propellant emerging from the composite motor and merely a large fire ball from the double base propellant motor.

Since composite propellants have shown this insensitivity, no correlation between motor size and equivalent TNT yield has been established. However, two tests supported the theory that weight (and shape) of the donor is the major factor in determining equivalent yields. Two different motors, weighing 10,500 and 44,000 pounds, yielded TNT equivalents of 1,500 and 1,600 pounds respectively when initiated by identical donors. This emphasizes the requirement established in critical diameter tests that the donor and acceptor charges must both exceed a specific diameter in order to propagate a detonation front through the acceptor. Additional tests, however, are required to definitely prove that a donor which does not produce complete detonation of a segment of a motor will not produce complete detonation of the entire motor. In other words, if a 25 pound donor yielded a TNT equivalent of 1,000 pounds with a 5,000 pound segment of a motor, then a TNT equivalent of 1,000 pounds should exist for the complete motor.

Additional evidence for this theory was also sought from tests with polyurethane propellant MD-1 (Genie air-to-air-missile) motors. They were selected primarily because of their availability. Various weight charges of C4 ranging from 4 to 13.5 pounds were detonated in contact with the motors. The test results indicated that location was quite important. Identical donor weights yielded a two-fold increase in contribution depending upon location. Furthermore, equivalent detonations did not exceed 20% of the grain weight. Additional interpretation of the data, however, was difficult since a large amount of scatter was present. This was accounted for by the low yields which are masked by the wide equivalent detonation correlation band. Figure 2 presents this band on a graph depicting the Edwards Test and calibration data superimposed over the Ballistic Research Laboratory curve for spherical pentolite.

The method to determine the detonation equivalents was initially accomplished by TNT calibration charges in the range from 20 to 700 pounds. From these tests, a coefficient of reflection was established which was a ratio of the measured TNT weight (using the BRL date) to the actual TNT weight. The low calibration charges, however, presented a reflection coefficient which appeared erroneous. Subsequently, it was decided to calibrate the test area with TNT charges up to 5,000 pounds. From these tests, a sliding reflection coefficient was measured depending upon actual overpressure. This lowers some of the original TNT equivalent values since a fixed coefficient of 1.5 had been used; however, the data in Table 2 has not been corrected for this effect.

A visual observation has also been possible to determine if detonation of a motor occurred. In the case of a detonation a large, brilliant fireball was generated with no shooting fireworks. In the other case, a small dull cloud was formed out of which emerged large quantities of burning propellant similar to a 4th of July spectacular. This is shown in Figure 3 where a very low TNT contribution was recorded. (Test 60-18). Furthermore, not all the propellant was ejected in the burning state. Large quantities of unburned propellant were also recovered in the absence of a detonation. For example, after the test of a 20,000 pound motor, over 4,000 pounds of unburned propellant were recovered (Test 60-13). One of the unburned chunks, recovered at 100 feet, weighed over 50 pounds and is shown in Figure 4. This, by itself, indicates that a detonation wave was not sustained.

The burning propellant sometimes has exhibited another peculiar phenomenon. Where the burning fragments fell to the ground, a popping noise was heard, even from long distances. Inspection of the concrete test stand and roadways has also indicated numerous small pockmarks without burn stains. These effects were attributed finally to small pressure shocks generated by the propellant. This occurred when the burning propellant was shattered upon impact causing a sudden increase in surface area. This does not appear hazardous since the overpressures were not measurable, and the pockmarks never exceeded a few inches in diameter.

In addition to measuring overpressure, an attempt was made to calculate detonation velocities with pin gages and streak cameras. The pin gages were located at various distances from the donor, and were to short-out from the shock wave. This was then recorded on an oscilloscope with a time sweep. The only problem was that they indicated an ordinary pressure wave as well as a detonation wave. In the instances where there was no sustained detonation, they indicated erratic velocities ranging from zero to a few thousand feet per second. Since TNT detonation velocities are on order of 21,000 feet/second, the only conclusion made was that the pin gages were closed by an ordinary pressure wave through the propellant grain and not by a detonation wave. A better method has been to use a streak camera. This was done with the Minuteman polyurethane propellant in a 19" diameter Beauregard test. The streak picture is shown in Figure 5 along with the test set-up. The timing on the film was erratic and is not indicated. The slope (velocity) of the luminous particles through the encased ($\frac{1}{2}$" steel) propellant section is 0.193 of the slope through the Composition B high explosive. This compares with 0.554 for the slope of the particles through the free air above the charge. This indicates that the velocity of the shock front through the propellant was much less than through the air, and a detonation wave was, therefore, nonexistant.

The Beauregard test conclusively demonstrated that the present Minuteman polyurethane propellants have a critical diameter in excess of 19" (if indeed they have one). It further supports the conclusion that composite propellants of the conventional PBAA and polyurethane systems are relatively detonation insensitive. This is supported by over seventeen (17) detonation tests on composite propellant charges.

Although the detonation tests were predominant, several other types of tests were conducted. One of these was a series of launch destruct systems tests with the cone and linear shaped charges. Both types of charges were tested upon composite and double base propellant motors. The cone shaped charges were mounted on either the head or aft closures while the linear charges have usually been mounted along the cylindrical section of the case.

Of the two systems, the cone shape charge delivers a greater shock to the propellant. This was demonstrated by the only detonation of a motor not subjected to a detonation test. The motor contained a double base propellant and was destructed by a 4" diameter copper cone propelled by 500 grams of black powder. Linear charges have, however, not caused a high order reaction in double base propellant motors. This is undoubtedly a function of the critical diameter of the propellant, since the linear charge reacts over a relatively narrow but long area. No detonation reaction was observed with either destruct system on composite propellant motors. This includes destruct initiation of firing (Figure 6) as well as non-firing motors.

The objective of rupturing the case was accomplished in all tests. With the linear charge an interesting peeling action has been observed on non-firing motors. The entire case length cut by the charge has peeled open and then flexed shut again. Ignition of the propellant then proceeded at several localized areas, requiring in some instances several seconds to ignite the entire exposed propellant area.

Damage from the motors has been limited primarily to the test stand where heat distortion of the tie-down fixture was quite severe. Occasionally, a piece of propellant fell upon one of the many cables in the test area and burned it through. Similar effects were also observed with the bullet impact test.

The bullet impact tests consisted of firing high velocity or armour piercing bullets into the motors. In no instance was any detonation recorded, but ignition of the propellant occurred whenever the bullet penetrated the case. Occasionally, short bursts of propulsive thrust were recorded which approached the normal thrust level of the motors. Post test inspection of the cases in these instances revealed a hot spot on the wall directly opposite from the penetration point of the bullet. This lead to the conclusion that the bullet penetrated the grain cavity and impacted on the opposite propellant wall. Ignition

thereby occurred within the perforation which caused chuffing burning until sufficient surfaces of fractured propellant ignited and a pressure failure of the weakened case ensued. This was especially noticeable with double base propellants in fiberglass cases. The poorer propellant physical properties caused greater shattering, which combined with the severe weakening of a cut fiberglass vessel, caused a rapid pressure failure. Again the debris and shower of propellant to the surroundings was negligible and did not exceed a distance of a few hundred feet depending upon the type of motor.

The last type of test in this group was the fire test which was conducted on composite propellant motors up to 44,000 pounds and double base propellant motors up to 3,500 pounds in weight. The motors were ignited in these tests with a gasoline fire under the entire length of the motor. Ignition of the propellant usually occurred in three to five minutes, along the case wall, and caused a pressure failure of the weakened chamber. Not a single detonation or overpressure reaction was measured in these tests.

Fragmentation was negligible but the fire was quite intense. Telephone poles fifty feet away were ignited spontaneously; the sand on the earthen revetments was heated into a low grade of obsidian glass; and the surfaces of the concrete slabs used to protect the test stand floor and buttress wall were turned into a molten slag. Peculiarly enough, the metal test stands were not severely damaged; although, the distortion from the heat rendered parts useless.

All foregoing tests caused some reaction from the propellant which may be considered a hazard. There was, however, one test conducted where no reaction ensued. This was the drop test of a composite propellant motor. The drop test was performed on the Skybolt Stage I motor, weighing 5,400 pounds. It was dropped ten feet upon concrete to simulate an operational accident. The case was cracked, but no fire or detonation ensued.

Conclusions

The tests have indicated that hazards were presented by three different propellant reactions. The first was a detonation reaction usually resulting only from a high explosive donor which exceeded the critical diameter value for the propellant. The reaction was primarily limited to double base propellants. The distance to which a hazard was present in this case is determined by the shock overpressure.

The second reaction was a partial explosion, where a detonation wave entered the propellant but rapidly dissipated into a plain shock wave. The reaction was associated primarily with composite propellant motors subjected to high explosive donors. The primary hazard was from

shrapnel and burning propellant scattered to some distance. The calculated distance to which a hazard exists must, however, be based upon a statistical density and energy of fragmentation and will be much less than the maximum distance of shrapnel.

Finally, the third, and least hazardous reaction was the ignition of propellant through an insititous cause. This hazard mode usually occurred during the tests where a high explosive donor was not present, irregardless of propellant type. The fragmentation distance depended upon the chamber pressure prior to case failure, but the chamber usually was weakened to the extent that fragmentation distances were small. The distance to which a hazard exists for this reaction is based upon the radiative heat of the propellant which may spontaneously ignite the surroundings.

Bibliography

1. Tommy W. Gordon, Capt., USAF, Hazard Classificstion Tests of GAM-87A First Stage XM-80 Motor and Second Stage XM-81 Motor, SSD-TR-62-13, January 1962.

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3. DGS and Boeing Test Reports for the individual Minuteman et al tests.

Table 1

TEST	ITEM	MNF	PROP*	PROP. WT.	H.E. WT.	DETONATION YIELD
311	MM III SS	HPC	D.B.	507	5	COMPLETE
312	MM III SS	HPC	D.B.	498	$\frac{1}{4}$	"
321	MM III SS	HPC	D.B.	493	3	"
	MM III SS	HPC	D.B.	493	–	"
315	MM II	AGC	P.U.	10,500	100	2500 lbs
60-18	MM II	AGC	P.U.	10,500	25	500 lbs
60-20	MM II	AGC	P.U.	10,500	–	2200 lbs
	MM III	HPC	D.B.	3,500	5	complete
60-6	MM II	TCC	PBAA	10,500	100	1500 lbs
60-15	MM I	TCC	PBAA	44,000	100	1600 lbs
60-7	MD-I	AGC	P.U.	250	$4\frac{1}{2}$	50
-8	MD-I	AGC	P.U.	250	9	40
-9	MD-I	AGC	P.U.	250	6-3/4	26
-10	MD-I	AGC	P.U.	250	$4\frac{1}{2}$	30
-12	MD-I	AGC	P.U.	250	$13\frac{1}{2}$	20
60-13	SI	AGC	P.U.	19,000	100	800
60-16	BEAU	AGC	P.U.	1,400	700	400
60-17	BEAU	AGC	P.U.	1,400	700	450
60-2	S-III	ABL	D.B.	2,000	DEST.SY(500 Gr.)	COMPLETE
61-1	S.B.	AGC	P.U.	2,710	$\frac{1}{2}$	NONE
61-2	S.B.	AGC	P.U.	5,472	$\frac{1}{2}$	NONE
62-14	S II	TCC	P.S.	7,300	2,984	NONE
62-15	S II	TCC	P.S.	7,300	$\frac{1}{2}$	NONE

*D.B. = Double Base
P.U. = Polyurethane
P.B.A.A. = Polybutadine Acrylic Acid
P.S. = Polysulfide

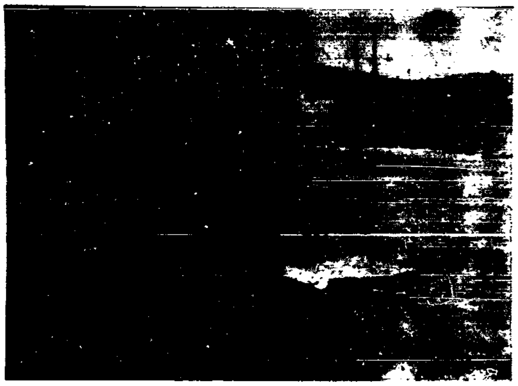
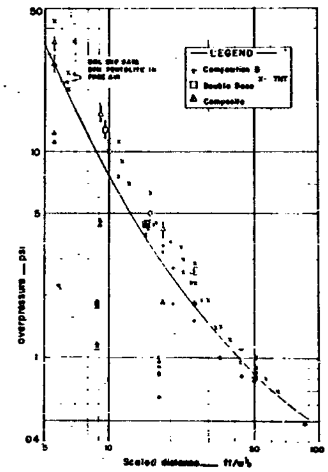


Figure 1



DETONATION EFFECTS

Figure 2

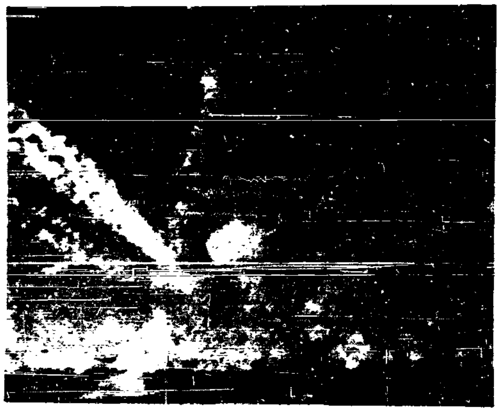


Figure 3

Figure 4

Figure 5

Figure 6

Mr. Bishoff: You mentioned the reject third stage of the Minuteman which detonated completely. You said it was the reject, could you give us some more information on why it was rejected, the extent of the porosity, and why we should disregard the detonation.

Lt. Hasselmann: It wasn't the third stage, it was the second stage, polyurethane propellant motor. This motor had been in the curing oven and as you know the second stage Minuteman has a bi-propellant grain, a cast first grain and it was sitting in the casting oven in a casting pit when a fire broke out and they deluged the motor. At first the propellants were completely deluged, they tried to clean out, to cast the second layer of propellant in there. At the time the Minuteman program did not have enough motors, they were very short on motors and rather than completely scrap the motor, they decided "let's at least use it for a detonation test" and I'm sure they're sorry they did now. In addition, they did not take any X-rays of this motor because they felt it was in such bad shape but a companion motor which was sitting in the same casting pit, they did take X-rays and it showed severe porosity and I think there were holes up to about $\frac{1}{4}$" in dia. and it extended for several inches inward from the case. In addition, this other motor had approximately 60% of the head end unbonded from the case. This was just an example of the severe unbonding and the porosity of this motor, altho they did not take X-rays of this motor that had a high order reaction, they feel it was just as bad as the other motor, if not worse. And I think this points out another thing, if you want to run a test, be sure to have a good motor.

LCdr McArthy: In your bonfire tests, were the nozzle throats plugged to prevent the flame from getting up in there and igniting the propelland and did you measure any net thrust?

Lt. Hasselmann: I think they just had a plastic cover on them.

Unidentified: The reason that I can answer that I instrumented it and put up the range and also conducted the fire test. The trough underneath was made of such a length that the flame could not lap over into the throats. The reason that you did not see the flame coming out of the nozzles was that you hadn't gone thru into the grain, the grain was burning on the outside. As soon as it ignited in the center of the grain, then of course you saw this, but the flames were not allowed to lap in, in other words, the trough was made short enough and as far as any plugs in it, the only thing that was in there was a small polyurethane foam piece.

Lt. Hasselmann: The pan of gasoline extended the entire length and you are quite right, it did not go.

Unidentified: Did you attempt to make any plot of the fragmentations and also weigh the fragments and get some criteria concerning shrapnel and missiles?

Lt. Hasselmann: We did to a certain extent, the reason I did not put these figures down there, it's strictly from the point that people may misinterpret them. It depends strictly on the type of initiation you have as to your fragment distance and whether you initiate 100 pounds of Comp. B on the side of the motor or at the head of the motor makes quite a difference in your fragmentation pattern. Rather than saying for a detonation reaction of 1500 pounds, our fragmentation pattern was so much, I'd rather say you tell me how you will initiate it and I can try and get the data that you need and say in this distance, it went so far. We did record weights, of course, this was difficult, you had to scour the area and after running about three or four of these tests, it was hard to pick out which was new shrapnel and which was old shrapnel. It is not as extensive as I'm sure many of you would hope it to be.

Dr. Zernow: I'd like to suggest a correction to the impression that the second stage Minuteman actually resulted in a detonation. I think the best one can say for that experiment is that the data is inconclusive. There was no electronic instrumentation available to give reliable data. The data from the Bikini gages varied widely, there was unburned propellant found and I would say also that if there were a full detonation in that system, one would certainly expect to get yields in excess of 100% TNT equivalent and even the Bikini gages at their extremes did not give that.

Lt. Hasselmann: That's why I said it was a high order reaction. We measured on our Bikini gages greater than 22% but there was a lot of scatter in the data.

Mr. Philipchuk: There was a bullet impact test I believe on a Minuteman, it appeared to be a chugging and then a burning reaction. What type of grain was in that motor and what projectile or bullet was fired against it?

Lt. Hasselmann: I'm not sure offhand whether it was a .30 or .50 cal., it was one of the two, it was a Minuteman third stage with a double base propellant, XM57 I believe.

Unidentified: That was a caliber .30 projectile that was fired into that thing. There was something else, on one of the tests that was conducted on the third stage I think you have it listed as ¼ pound, I think that was actually 20 grams of tetryl. I think it was the second firing and I noticed also that you did not have a sympathetic detonation test.

Lt. Hasselmann: I had them listed together.

Unidentified: It's pretty interesting that we were 7,200 ft. from the test stand and an A frame weighing 75 pounds wound up at 5,280 ft. in front of us, so you can see what happens when one of these things goes.

Lt. Hasselmann: There's something I'd like to bring out that you just mentioned. Just because you have one piece of shrapnel going that far, you really can't consider this as a hazard, because you have a 360° arc. Sure, it may hit you, but the probability of it hitting you is not very great.

Dr. Ball: Just to keep our semantics straight here and to answer in part Mr. Philipchuk's question, the propellant in this is a double base binder composite propellant, double base itself is a homogenous propellant single phase. The crystal and oxidizers used in this is a mixture of AP and HMX. This information is classified.

QUANTITY-DISTANCE STANDARDS FOR SOLID PROPELLANTS IN AMOUNTS ABOVE 500,000 POUNDS

by
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Armed Services Explosives Safety Board

I am not going to talk primarily on the subject as listed in the agenda you were given. We have a work group that is considering this matter. We had two meetings and achieved general agreement on certain principles but I think the meetings primarily pointed up the need for such further work in this area which has again been emphasized by the preceding three presentations at least.

In general this work group agreed to recommend simple extrapolation of existing quantity-distance tables, except for inhabited building distance for detonable high energy propellants. At the present time for those detonable propellants, not all of the members were willing to accept a distance of $D = 70W^{1/3}$ for the inhabited building protection. That was the maximum recommended and is in our standards. Not all of this group were willing to accept $D = 58W^{1/3}$ - a minimum figure acceptable to the majority of the persons present at the two meetings. Now with respect to other distance figures - for Class II propellants the existing tables would simply be extrapolated according to the formula $8W^{1/3}$ for inhabited buildings.

For those propellants that have been proven or are assumed to be detonable the mass detonating quantity-distance tables of DOD Directive 4145.17 would be extrapolated upward by the formulae contained in that directive, i.e., on an unbarricaded basis, for example, you would have a magazine distance of $11W^{1/3}$ and intraline distance of $18W^{1/3}$. As you also know the directive does not permit taking credit for barricades for inhabited building distances above 250,000 pounds.

Now in the deliberations on this subject there was much discussion about what to do with those propellants which do produce distant blast pressures but appear to be only partially detonable.

Perhaps here I should say that the subsequent remarks are my own opinions and are not necessarily those of my sponsor. I worked this up hurriedly on the basis of some data recently obtained and I want to talk about the widespread interest in attempting to rate these propellants, those that are partially detonable, by means of a high explosive yield on a percentage of the total weight. Most of the reported figures that have been used in this high explosive yield concept are in the area of 5 to 40%.

I would like to show you a movie and review some data that I think indicate that this high explosive yield concept may be dangerous unless it is much more exhaustively proven than has been done to date. I might suggest that proving it sufficiently for some situations might be more expensive than for the die-hards to throw in the towel and simply buy enough land to use Class 10 distances. I am not suggesting that this will always be the case.

One of the last remarks on the sound track of the film is that if the propellant did not contribute 100% this damage was wrought by somewhat less than 425 pounds of high explosive.

Most of the high explosive yield figures that have been reported on various weapons or systems have been based on a relatively small number of experiences. In some cases a determination has been made on one or two full scale or large sub-scale tests.

We have, however, one particular weapon system, the one you just saw the movie of, upon which we are beginning to accumulate a rather large amount of experience - that is, the Air Force MB-1, previously shown in the movie and last year in another dividing wall test. The experience with this weapon shows high explosive yield figures ranging from 0 to more than 100%.

One special set of tests was performed by the Naval Ordnance Test Station for the specific purpose of trying to resolve this difficulty of evaluating the high explosive yield of this weapon.

Ten calibration shots were fired using Comp. B billets up to a weight nearly equal to the total explosive content of the MB-1. On the basis of partial data the peak pressures obtained follow a cube root law and generally seem in accordance with existing theory. I compared them with a curve for surface bursts of TNT and they appeared to be quite close to what you would expect. There is some scatter to the data but not nearly as much as on some other tests. This tends to confirm the technique of measuring, reading the gages, etc.

Subsequently they fired nine shots using a fully assembled missile with a warhead sphere, again on the basis of partial data but obtained under identical conditions to the Comp. B experience just described and there was no agreement. One shot yielded peak pressure values equal to those for an equivalent weight of Comp. B but several of the test shots indicated values approximately equal to those for the warhead alone. Previously there had been run a series of hazard classificaion tests on this weapon, ten shots which failed to produce any significant blast pressures, therefore, no reportable HE yield. These were in accordance with standard hazard classification test criteria with a high explosive boost very much less than that provided by the weapon warhead.

Another series of tests which Lt. Hasselmann touched on included 15 impact vulnerability tests which resulted in several cases of so-called low order detonation of the propellant and burn tests which were also said to result in low order detonation of the propellant. For this series in nine cases of detonation, it was reported that there were TNT equivalents ranging from 110 pounds to 400 pounds, three of the nine being in the vicinity of 400 pounds.

On the first dividing wall test of this weapon which was described at last years seminar, observers computed a high explosive yield of 512 pounds of TNT. So on a total of at least 35 shots, this weapon has given such erratic results that the quoting of a high explosive yield figure appears to be meaningless.

Most observers in the business agree that as you increase the size and HE boost for a solid propellant system the prospects for a partial detonation of the propellants increase. If we get the same erratic behavior on larger systems, which doesn't at the moment appear unlikely, it seems to me we could make very dangerous errors by rating a low HE yield for a propellant from the small number of full or large sub-scale tests that are currently being talked about for this type work. That is about all I have to say on this subject as far as the disagreement is concerned. I think it was quite well covered by Dr. Amster, Lt. Hasselmann and others.

Mr. Couch: Has any action been taken on the recommendations of the work group for the quantity-distance of solid propellants above 500,000 pounds?

Mr. Perkins: Not with respect to getting formal Board approval of the things that I said here. In other words it's still in the status of the work group's recommendations.

Mr. Couch: Is there any plan to do this?

Mr. Perkins: Yes, there very definitely is. But you recall that one of the recommendations of the work group was to develop test procedures to determine some of the answers to these unknowns and what my purpose was here this morning was to try to point out that this is a very definite need.

Mr. Couch: But the quantity-distance doesn't have to wait action on the other does it?

Mr. Perkins: No.

Lt. Hasselmann: I'd like to emphasize on something that I mentioned that seems to be indicated in these tests that you mentioned. Namely,

that you're going to have to take a good motor in order to run your tests. We got the same scatter on our MB-1 data and at first we were unable to explain it. However, we did a little soul-searching and Stanford Research Institute ran an aging program about two or three years ago on this 512 propellant in the MB-1 and it turns out that this propellant gets very brittle with age, and as a result, the Air Force right now has curtailed the temperature limit under which you can use this missile after it gets certain ages. This result, this large scatter I think is probably due, in some extent, to the overage motors and I believe you did use overage motors, at least we did. So that if you really want to get good tests, you're going to have to get motors that will represent your actual conditions and not something that has been rějected. This points back to the thing the Minuteman program did where they tried to cut corners and it just didn't turn out that way.

Mr. Perkins: I'd like to make one comment. It's true that they took from the stockpile items that were due to be retired because of age. It is also true, however, that they did not take stockpile weapons that had been retired for unserviceability and were known to be bad. Also, there are many anomalies in this data which appear for the individual weapons, directionalization of the pressures, failure to get comparable results between gages at 30 ft. and 50 ft. where they did get comparable results with the gages set on the HE calibration that cannot be explained by saying that the motors were defective.

Dr. Price: I wanted to take some exception to two terms that Mr. Perkins used. I think most of us understand what was meant, but I think as people come into the field, they can cause a great deal of confusion. I think in so-called "partial detonations" and so-called "low order detonations," you have nothing of a detonation, at least in say 95% of the cases, the detonation is a steady state phenomenon and I think you would have been able to reproduce your test results had you been detonating. What I think most of these incidents are, is a very fast explosive combustion and I think the rate and the amount consumed depending very much on the shock loading of the material that initiates the burning. And I think in some cases your directional effect might be traced also to that shock loading. Whether it's best to measure these things in terms of a TNT equivalent certainly you do have a contribution over and above the detonation of your donor in these cases and you can measure them on the gages. Now whether it's simple or not to measure it as a TNT equivalent I don't know.

Mr. Perkins: I merely was trying to point out that it is extremely difficult to tell when you have reached a maximum TNT equivalent for a given system.

Dr. Zernow: I think perhaps the term reactive shock might be acceptable to everybody in accounting for these partial detonations. The

steady state detonation surely is not attained but yet you can get energy released as if the detonation were occurring but at a rate which decreases as time goes on as the shock case is not a self-supporting situation. I'd like to point out, however, that whether or not you get the dying detonation or the reactive shock or whether you get a yield from parts of the propellant far away really depends on this characteristic which we prefer to call critical geometry. Because an understanding of the critical geometry will tell you whether or not and how far that reactive shock will either propagate and die out or turn into a sustaining reaction. So I again emphasize the need for understanding the critical geometry concept in this case and also I certainly agree with Mr. Perkins that the question of assigning a TNT equivalent yield to a propellant regardless of the configuration which you find it in doesn't make a bit of sense.

Mr. Perkins: I am somewhat more interested in the reactions that take place, 100, 200 or maybe 15,000 ft. away from the incident than I am on what happens inside of the substance. I accept the corrections with respect to whether this is a detonation or not but also I'd like to point out with respect to Lou's comment here. I picked this series of tests because there was exactly the same test geometry on the 35 tests and the results apparently varied almost as much as if you had had 35 separate test geometry. This is almost a literal fact.

Mr. Charles J. Donlan, Associate Director of Langley Research Center made some brief remarks regarding the tour of Langley on Wednesday afternoon.

SAFE CHARACTERIZATION AND PROCESSING OF A NOVEL ENERGETIC PROPELLANT[1]

by
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An extensive effort is currently being directed toward the development of higher performance rocket propellants and propellant ingredients. A significant portion of this effort is concerned with the discovery, synthesis, and development of novel energetic chemical compounds and formulation of propellant compositions containing these compounds. An increasingly important part of the development of new propellants is the evaluation of their potentialities and problem areas at an early stage of development. It is usually required that the initial evaluation be made with small quantities of propellant because of the high or unknown hazards of the material and because of the high cost and limited supply of raw materials, which are usually produced on the laboratory or small pilot plant scale.

An example of a novel energetic propellant ingredient is 2,3-*bis*-difluoramino propyl acrylate (NFPA), an acrylic monomer of potential interest as a binder for solid propellants. The structure and some properties of this compound, which was first synthesized by Rohm & Haas Company, are shown in Figure 1. The molecule contains two NF_2 groups in a six carbon chain. Laboratory investigation indicated that this compound could be safely formulated into propellant compositions containing aluminum and ammonium perchlorate. Thermochemical calculations indicated that the theoretical equilibrium specific impulse of such compositions was in the range of 265 lbf. -sec/lbm.

A program to characterize NFPA propellants more thoroughly was undertaken. Emphasis was placed on obtaining accurate data on a wide range of properties from relatively small quantities of propellant.

A single composition, designated SA-1 and shown in Figure 2, was selected for evaluation based on processing, safety, and performance considerations. The safety information that was available for the monomer and for the propellant composition at the beginning of the evaluation is shown in Figure 3.

A two-pound capacity mixing facility was designed and installed for processing NFPA propellant. In order to reduce the yield losses

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[1]This work was performed for U.S.Army Ordnance under Contract No. DA-01 021-ORD-11878.

incurred in a separate deaeration vessel, a vacuum mixer was used. The mixer was a jacketed stainless steel vessel equipped with a flush bottom valve, thermowell, and flat bladed turbine agitator. A glass top on the mixer contained the agitator shaft seal and openings for charging of the raw materials to the vessel. Monomer was fed by gravity into the mixer. The solids were fed through pneumatically powered vibratory hoppers. Figure 4 is a flow sheet of the operation; a picture of the mixer and associated equipment is shown in Figure 5; Figures 6 and 7 contain details of the flush bottom valve and the agitator shaft seal, two critical items from the standpoint of safety. The manufacturing process included the following operations: (1) charging the monomer, initiator, and inhibitor to the mixer; (2) agitation for 10 minutes to dissolve the initiator and inhibitor; (3) addition of aluminum while agitating; (4) addition of oxidizer while agitating; (5) vacuum mixing for 10 minutes; (6) manually controlled casting; and (7) curing in a nitrogen atmosphere at 110 to 120°F. Steps 1 through 5 were carried out at ambient water temperature. Manually controlled casting was allowed because the operation involved only a mild disturbance of the propellant, the preliminary sensitivity data on the propellant indicated it had about the same sensitivity as propellants handled similarly, and the exploratory evaluation of several NFPA compositions had involved the manufacture of about 5 lbs. of propellant in more than fifty batches without any incident.

Twenty-one batches of SA-1 containing a total of 42.3 lbs. of propellant were mixed in the two-pound facility. There were two batch failures, one due to equipment malfunction and the other to casting and curing difficulties, and one partial failure due to contamination of a batch with cleaning solvent. Information on processing and quality control, sensitivity and stability, physical properties, and ballistic performance was obtained from the 19 successful (or partially so) batches. These topics are discussed in detail below.

Processing and Quality Control

The processing of SA-1 was straightforward except for complications imposed by the polymerization curing reaction. At the beginning of the evaluation an initiator system of 0.7% azo-isobutyronitrile (based on monomer), or AIBN, was selected to provide several hours pot life at ambient temperature and still assure a thorough cure in one day at 120°F. It was discovered, however, that nitrogen evolved as a product of initiator decomposition resulted in porous propellant in solid cylindrical charges of 1" diameter. Consequently, the initiator concentration was reduced to 0.1%. This worked satisfactorily except in small webs where oxygen inhibition prevented a complete cure. For this situation, a more powerful initiator (0.25% 2,4-dichlorobenzoyl peroxide) was selected together with an inhibitor (0.005% methylene anthrone) to provide ambient temperature pot life. This system was effective in overriding oxygen inhibition, but the high reaction rate might pose a

problem in larger webs where the heat of reaction (approximately 25 calories per gram) and accompanying exotherm (about 75°C adiabatically) become important. The curing shrinkage of about 6% by volume is another potential problem in case bonded configurations.

A valuable technique for the characterization of individual propellant batches, the evaluation of the quality of monomer lots, and the study of the effect of various combinations of initiator concentration, inhibitor concentration, and curing temperature was the measurement of curing rates by a dilatometric technique. With this technique small samples could be employed for accurate shrinkage rate determinations, the curing process could be observed over its entire range, isothermal conditions could be maintained easily, and the measurements could be directly related to the extent of cure. The major piece of apparatus employed in this measurement is shown in Figure 8. The procedure used in making a dilatometric determination involved weighing a sample (about 4 grams) of the propellant mix into a dilatometer bulb, after which the sample was degassed by freezing in liquid nitrogen, evacuating, thawing, refreezing, and re-evacuating. The dilatometer was then inverted, trapping the sample over mercury. The dilatometer was placed in a constant temperature bath and allowed to come to thermal equilibrium. Readings of the height of the mercury column were made at appropriate time intervals until no further change in height was noted. The volume change of the sample was obtained from the change in height of the mercury column in the attached capillary. From these data curves were drawn of the fraction of cure vs. curing time.

Specific gravity measurements along the axis of a cylinder of cured propellant showed that settling of solids ingredients was not a major problem with this formulation. The results of this test are shown in Figure 9.

Data on slurry viscosity, curing rate, physical properties, and residual monomer were obtained from the various batches. Values of these properties are shown in Table I in the Appendix. These data indicated that composition SA-1 was a low viscosity propellant; that the specific gravity of the cured propellant was reproducibly equal to the value calculated from the densities of the components, indicating that weighing, charging, and deaeration procedures were adequate; that a wide range of curing rates was available by proper choice of the initiator and curing temperature; and that the conversion of monomer to polymer was usually greater than 99%.

Several monomer batches were used in propellant. Though no formal specifications were placed on monomer properties, the chemical composition and polymerization rate in a standard test formed a basis for evaluating monomer quality. Table II in the appendix shows these properties for the monomer batches that were used in propellant. None of the monomer batches used caused any difficulties in propellant manufacture.

Hazard Evaluation

Card gap measurements were made on SA-1 in both the cured and uncured states. The cured charges tested included propellant initiated with 0.1% AIBN (specific gravity = 1.81) and 0.7% AIBN (specific gravity <1.5). These two kinds of charges did not give significantly different results. The results of the card gap tests are presented in Figure 10 along with comparable values for composition 112_{cb}, a composite double-base formulation with an extensive history of safe manufacture. The data indicated that SA-1 was less sensitive to shock initiation than 112_{cb} in either the cured or uncured state.

The excellent thermal stability exhibited by SA-1, even at elevated temperatures, was one of the most attractive features of the composition. A curve of time to explosion as a function temperature is shown in Fig. 11; a similar curve for 112 propellant is shown for comparison. The tests were conducted in 22 caliber cartridges. A test method for the evaluation of thermal stability of propellant compositions is the subject of a separate paper[1] being presented at this meeting.

Mechanical Property Evaluation

The mechanical properties of SA-1 were determined at several temperatures in a uniaxial tensile test using Rohm & Haas sample specimen no. 2 and a crosshead speed of 2" per minute. The results of these tests are shown in Figures 12, 13, and 14. It can be seen that in the temperature range of 78°F to 142°F both the strength and elongation of the propellant were very good; however, at temperatures below 78°F the strain capabilities diminished rapidly with decreasing temperature. The Charpy brittle point was about 65°F. These poor low temperature properties would severely limit the utility of this propellant in many missile applications. However, the improvement of low temperature capabilities through plasticization of the polymer is a well known technique that appears applicable to this particular problem.

Ballistic Evaluation

A significant advance in the small scale testing of solid propellants has recently been made through the use of very small static motors for the evaluation of propellant ballistic properties. It has been demonstrated that accurate measurements of ballistic performance can be made on motors containing as little as 10 grams of propellant and that from these measurements reliable predictions of performance in larger motors can be made. The measurement techniques and scaling theory necessary for the successful utilization of small motors have been

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[1]Booman, K. A., Thermal Stability of Solid Propellants

reported in detail elsewhere.[1] The manufacture of such small motors presented some interesting and novel problems. Fig. 15 shows some of the details of the hardware used in casting, curing, and disassembling these micromotors. Twenty-two motors ranging in size from 10 to 600 grams were fired for specific impulse determination. A summary of the data obtained is presented in Fig. 16. The data from the first 17 of the motors shown in the figure were used to predict a value of specific impulse for the 600 gram motor. The predicted value was 253.0 lbf. -sec./lbm. compared to an average measured value of 253.4. The theoretical equilibrium specific impulse of SA-1 expanded from 1000 psi to 14.7 psi is 266 lbf. -sec./lbm.

The above discussion demonstrates that modest quantities of propellant are adequate for the meaningful and accurate measurement of a wide variety of propellant properties. A particular propellant composition used as an example was found to have promising performance and safety characteristics. The anticipated improvement in propellant performance through the use of compounds containing the NF chemical bond was demonstrated experimentally.

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[1] Brown, L. M. and Cockrell, B. R., "Micromotor Evaluation of Specific Impulse," Bulletin of 18th Meeting of JANAF-ARPA-NASA Solid Propellant Group, June 1962.

Mr. Gallaghan: You mentioned that you lost some of the batches by mechanical failure, could you care to elaborate on this a little?

Mr. Parrott: I didn't intend to imply that there was any serious explosive incident in that particular batch, as a matter of fact, there was none in this entire program. One of the feeders failed to function properly and in attempting to correct this situation by adding solid to another opening into the mixer, the wrong amount of oxidizer was introduced into the batch.

Figure 1

Properties of NFPA Monomer

Formula -

$$\begin{array}{ccccccccccccc} CH_2 & - & CH & - & CH_2 & - & O & - & C & - & CH & = & CH_2 \\ NF_2 & & NF_2 & & & & & & O & & & & \end{array}$$

Molecular weight - 216

Vapor pressure - 0.3 mm. at 43° C

Density - 1.350 g/cc at ambient temperature

Figure 2

Composition of SA-1

Ingredient	Function	Wt. %	Particle Size
NFPA	binder	35	
APC	oxidizer	53	55 micron, 1% MgO coating
Al	fuel	12	8 micron

Polymerization initiator and inhibitor added as required.

Figure 3

Preliminary Safety Data on NFPA and Propellant

Impact sensitivity of NFPA[a]	35 kg-in.
Impact sensitivity of poly-NFPA[a]	15 kg-in.
Impact sensitivity of SA-1[a]	8 kg-in.
Adiabatic polymerization of NFPA	no fire
Bottle drop test of NFPA	negative
Atlas match test on NFPA	negative

(a) RDX = 9.5 kg. -in.

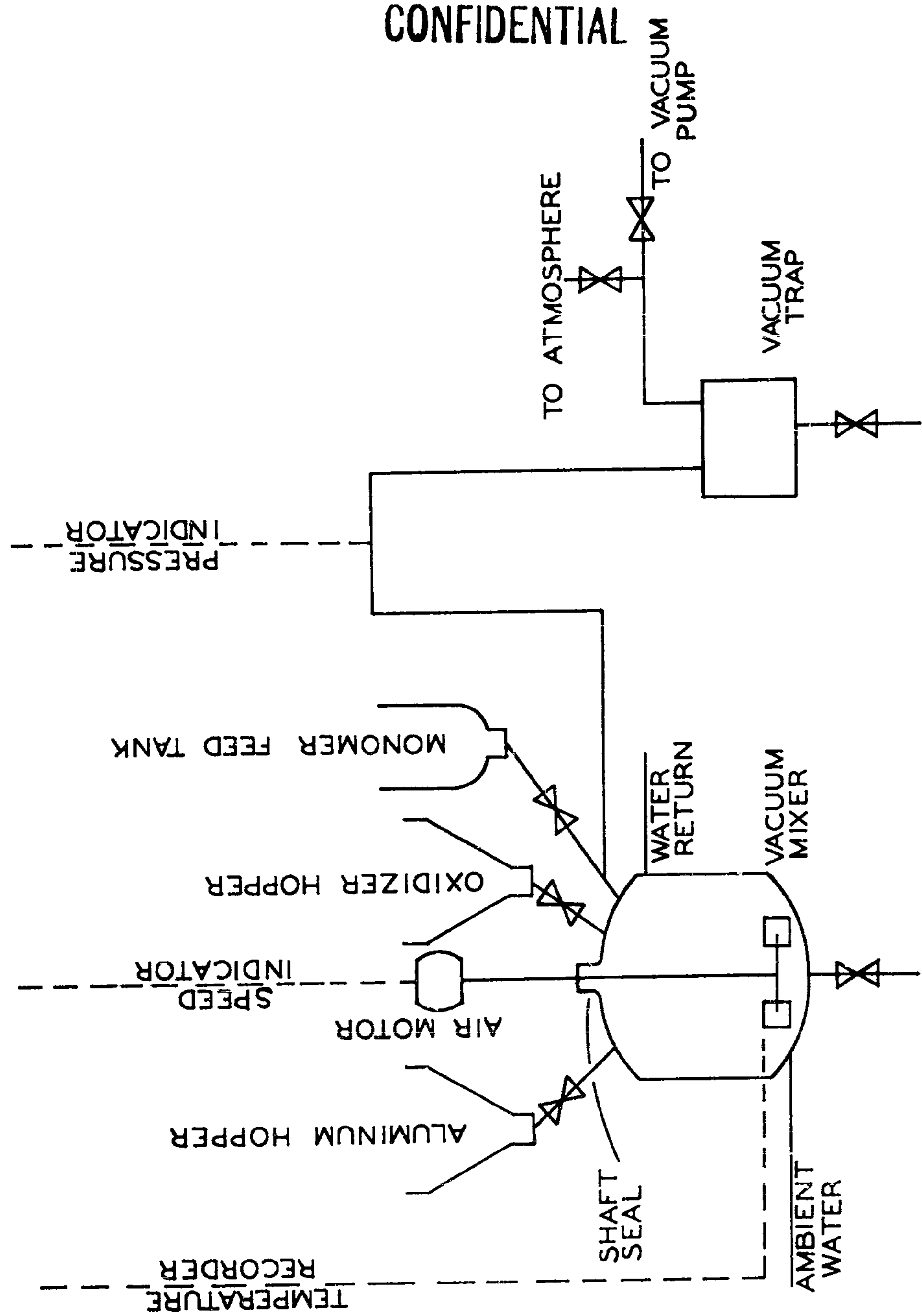

Fig. 4 Flow sheet for mixing NF propellant.

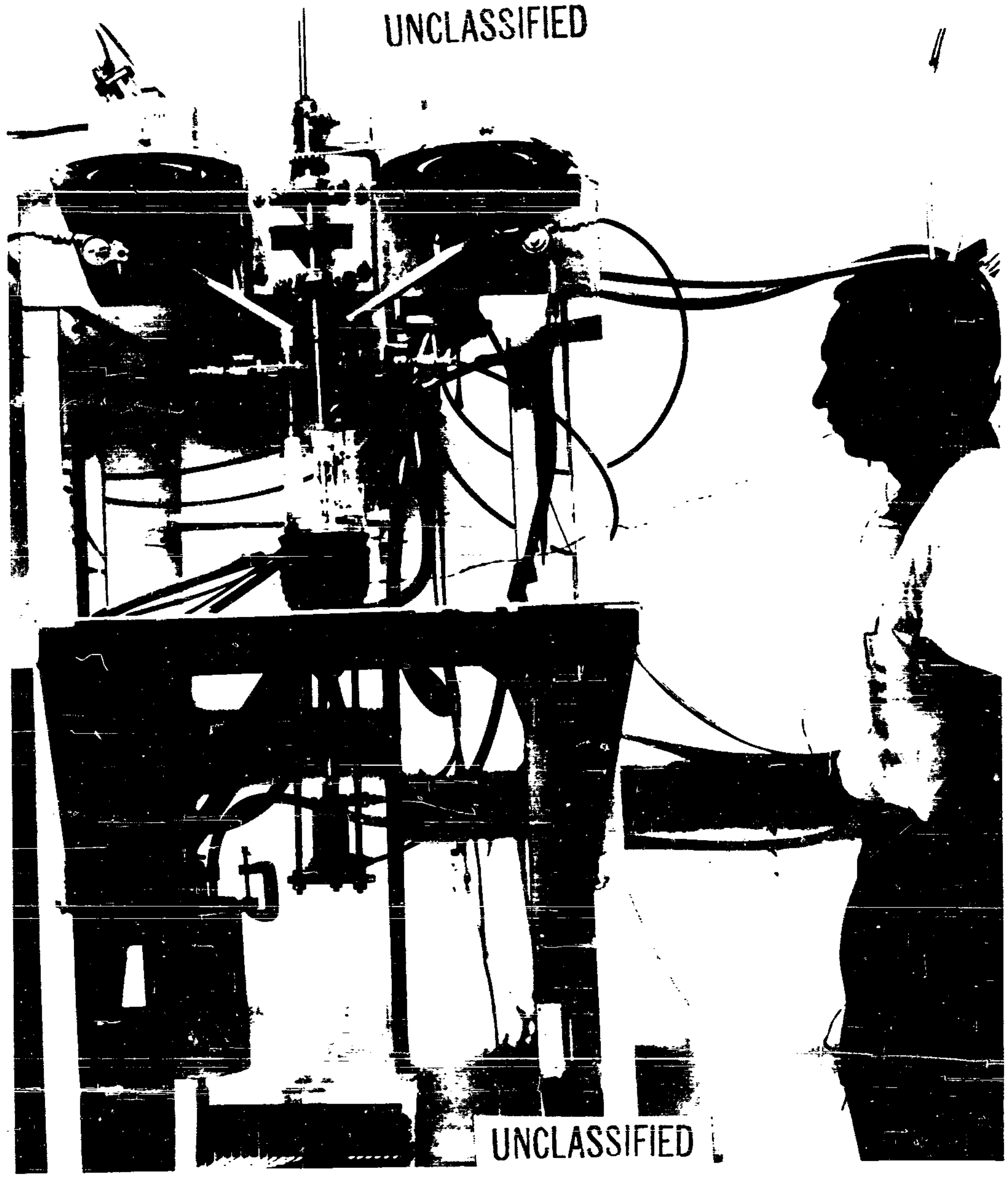

Fig. 5
Photograph of Two Pound Mixer Facility

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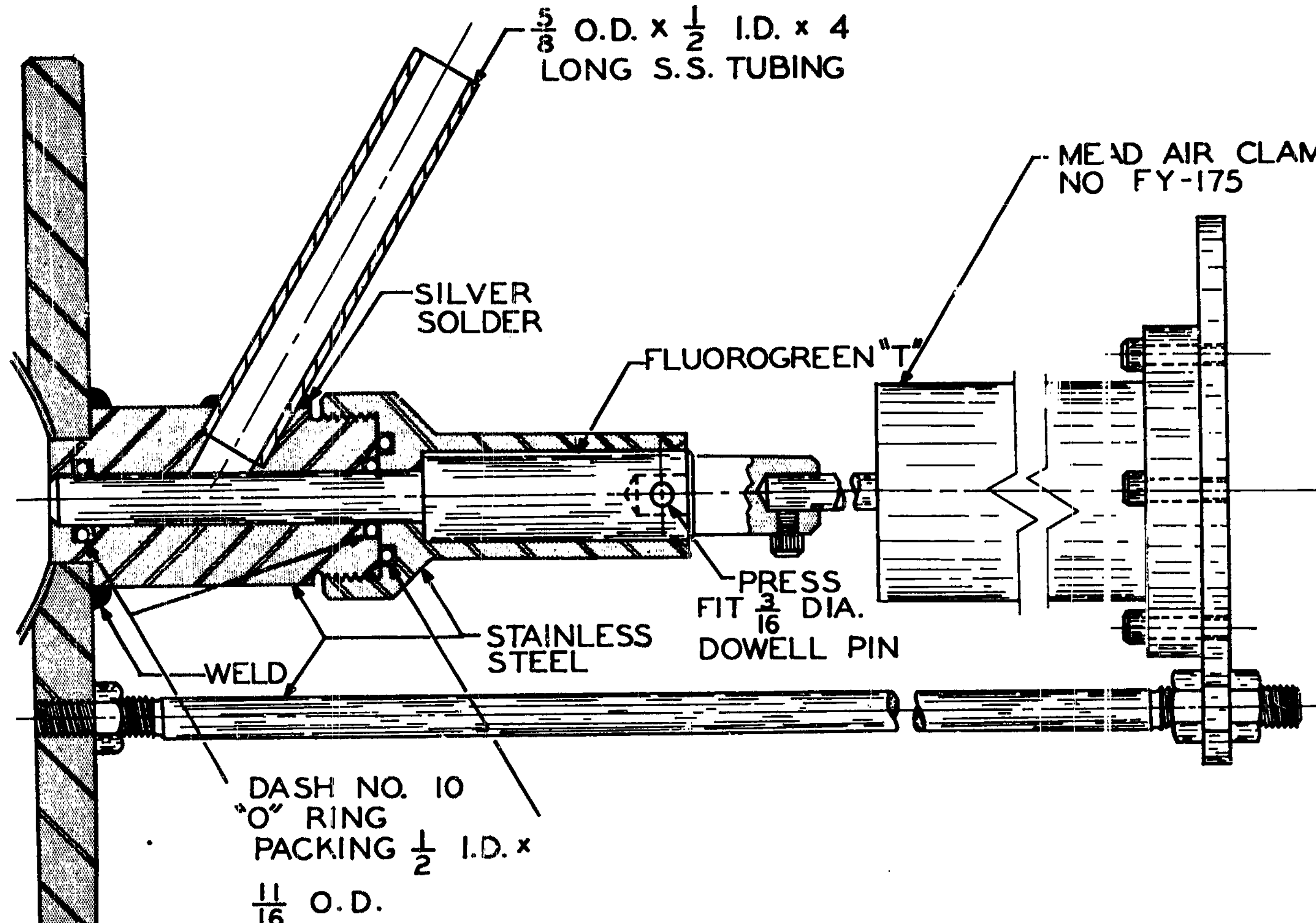

Fig. 6 Flush bottom valve details for two pound mixer.

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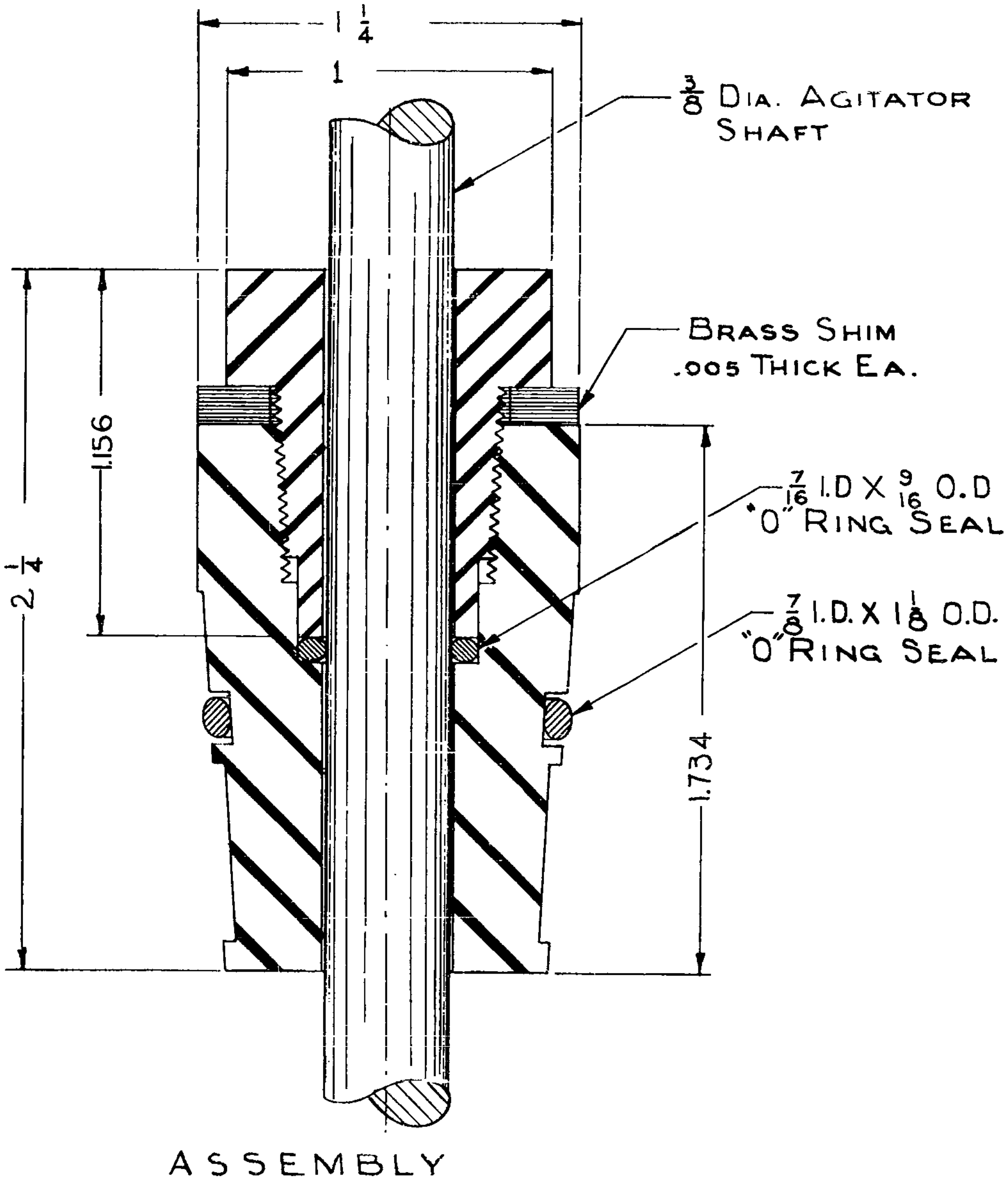

Fig. 7 Shaft seal details for two pound mixer.

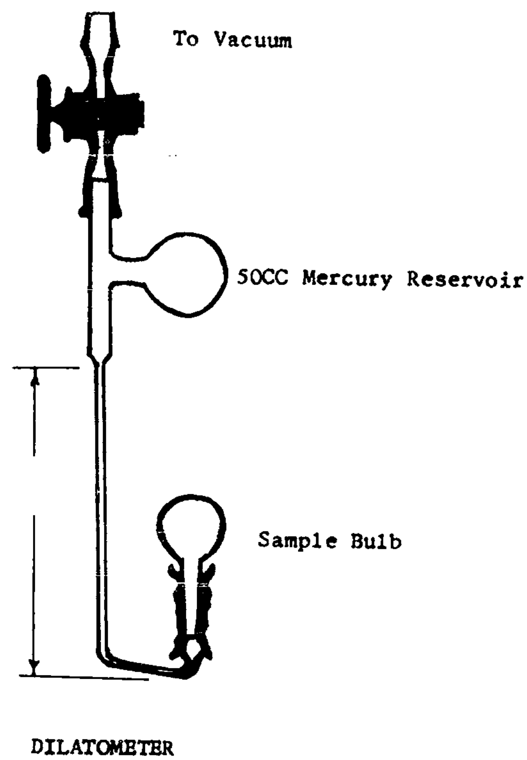

Fig. 8. Dilatometer for Curing Rate Studies

Fig. 9

Settling of SA-1

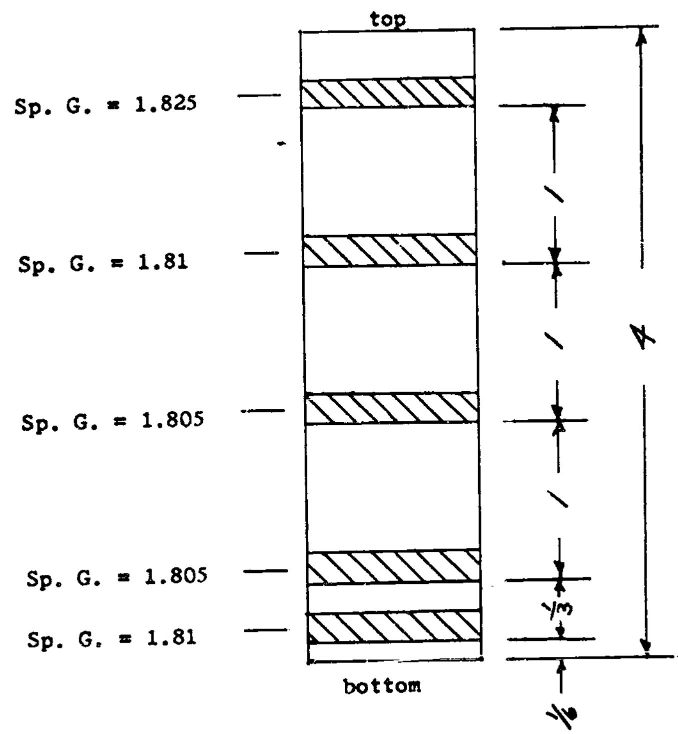

Figure 10

Card Gap Sensitivity of SA-1

Composition	Card Gap Sensitivity[a]	Minimum Diameter[b]
SA-1 (uncured)	72 cards - 0.6 in	0.36 - 0.62 inches
112_{cb} (uncured)	85 - 0.7	
SA-1 (cured)	20 - 0.15	0.62 - 0.82
112_{cb} (cured)	37 - 0.3	

(a) Measured in 1 inch diameter steel pipes using cardboard as a gap material.

(b) Measured in schedule 40 steel confinement.

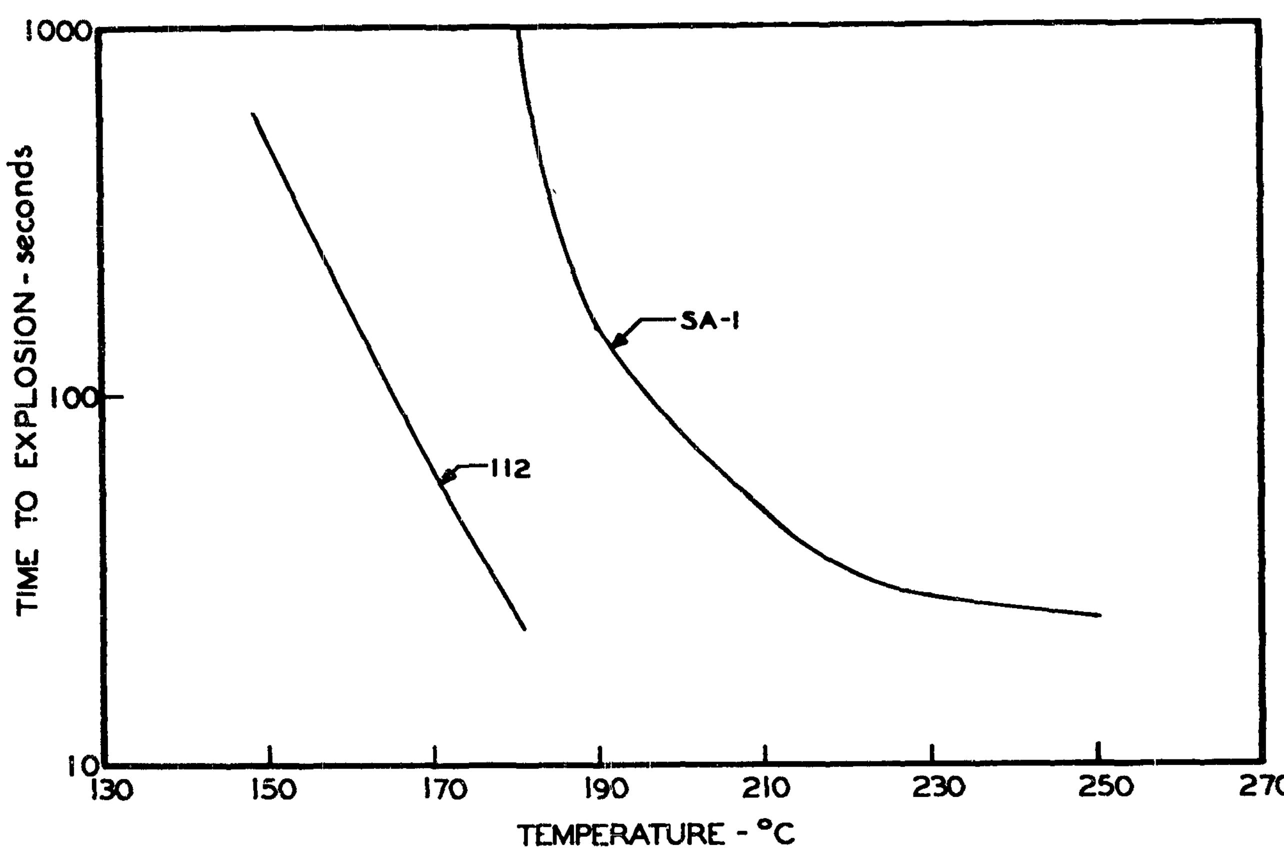

Fig. 11 Thermal stability of SA-1 propellant.

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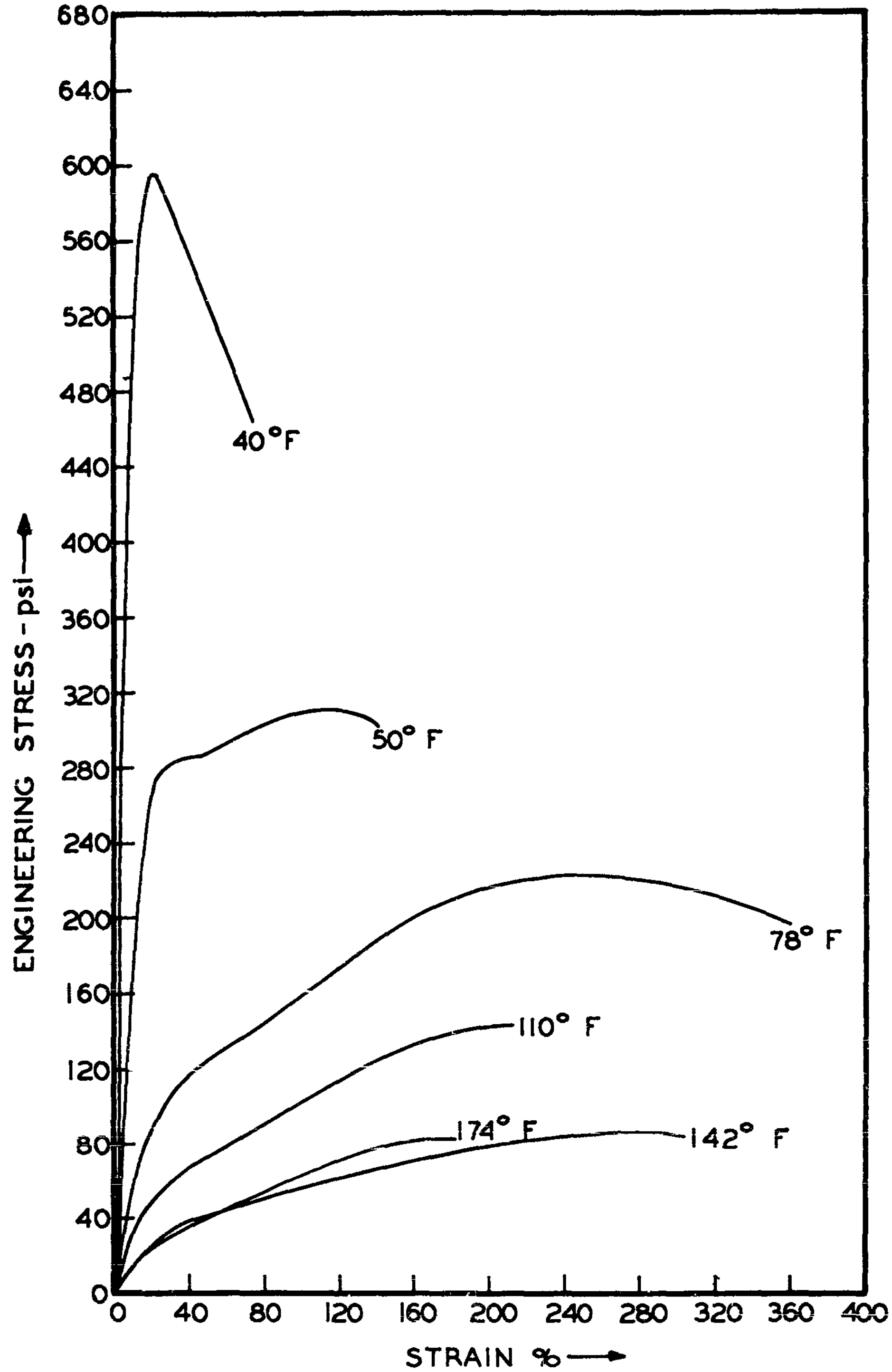

Fig. 12 Stress - strain curves for SA-1 propellant.

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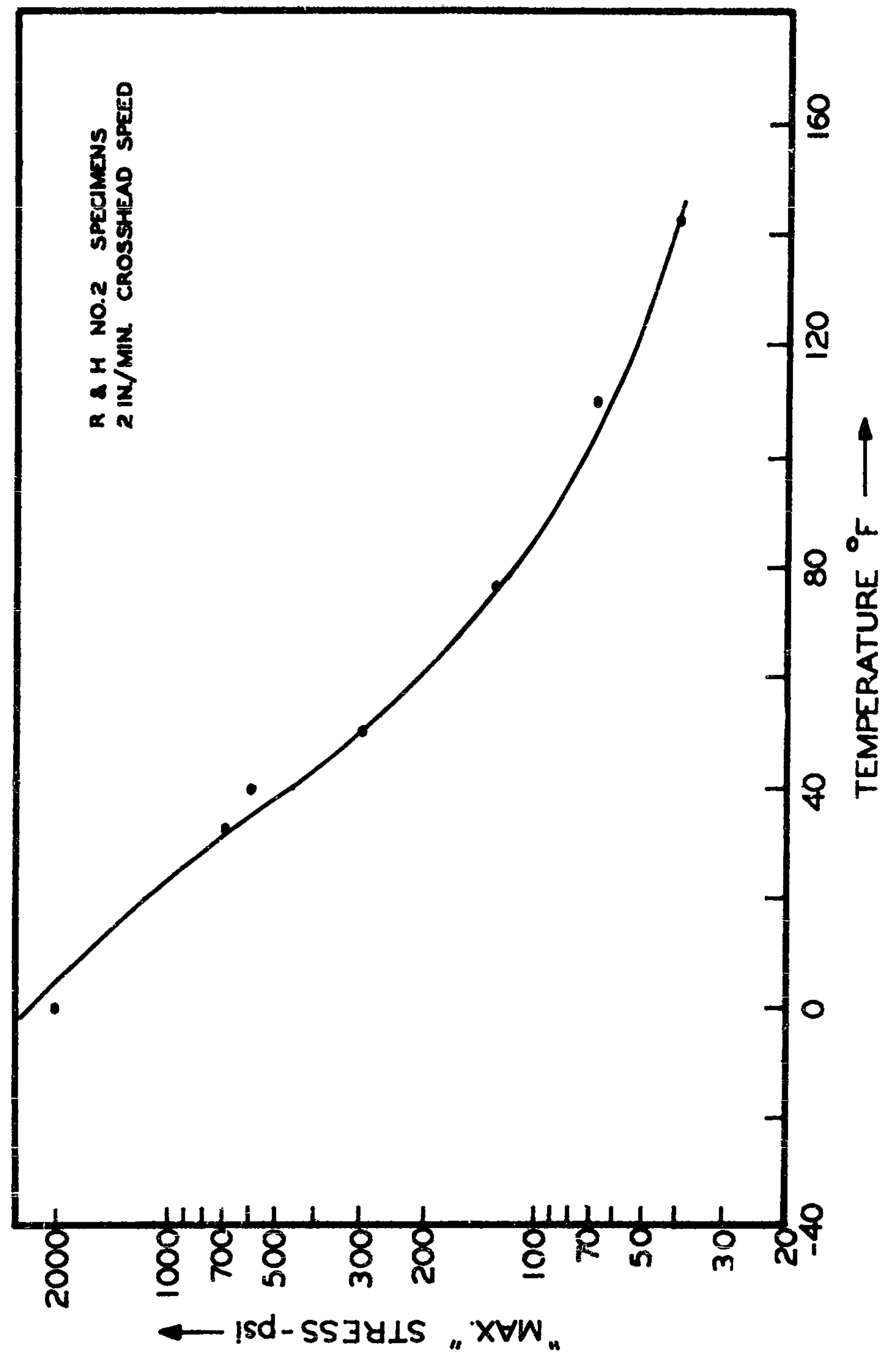

Fig. 13 Stress vs. temperature for SA-1 propellant.

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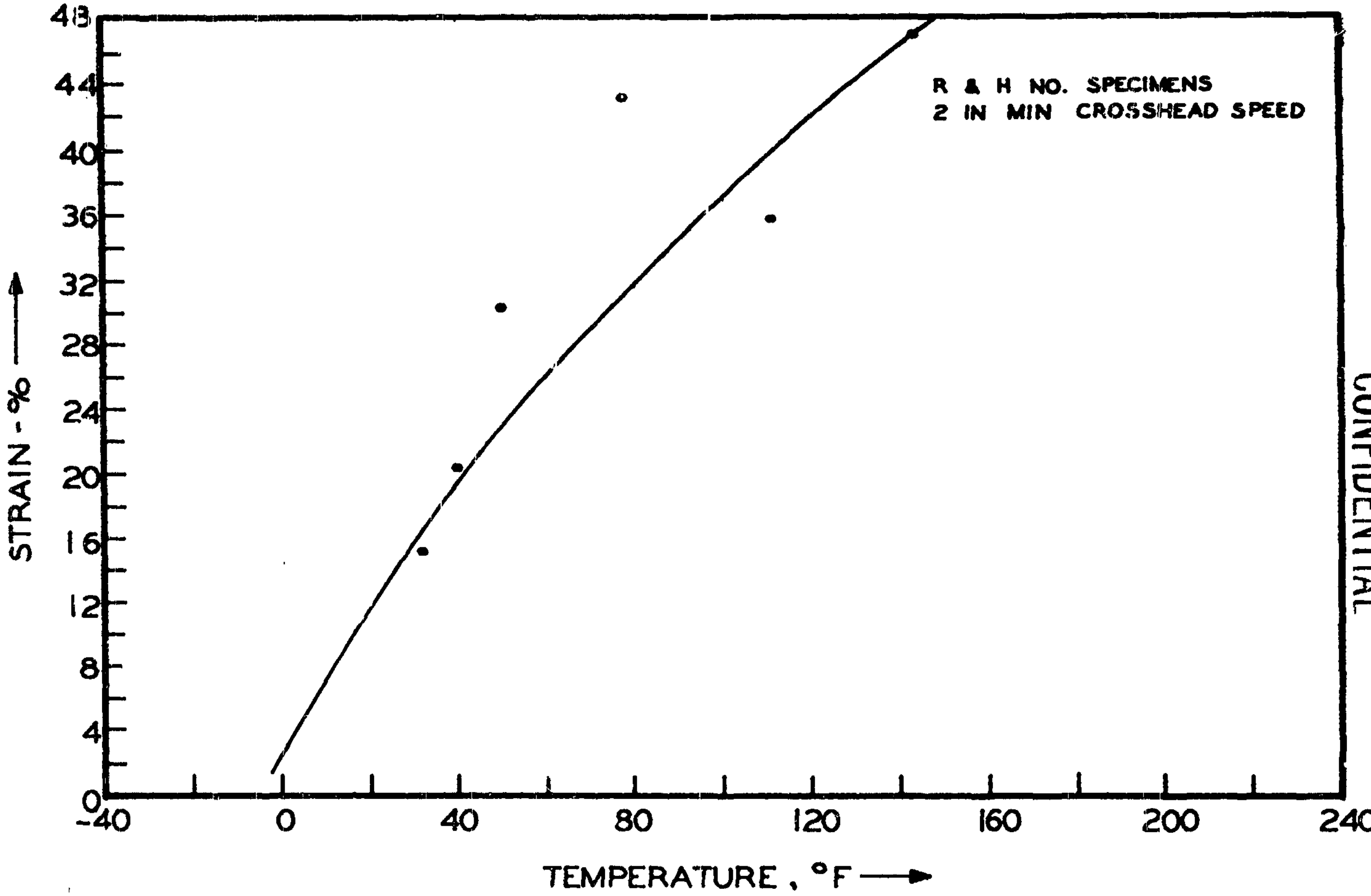

Fig. 14 Strain vs. temperature for SA-1 propellant.

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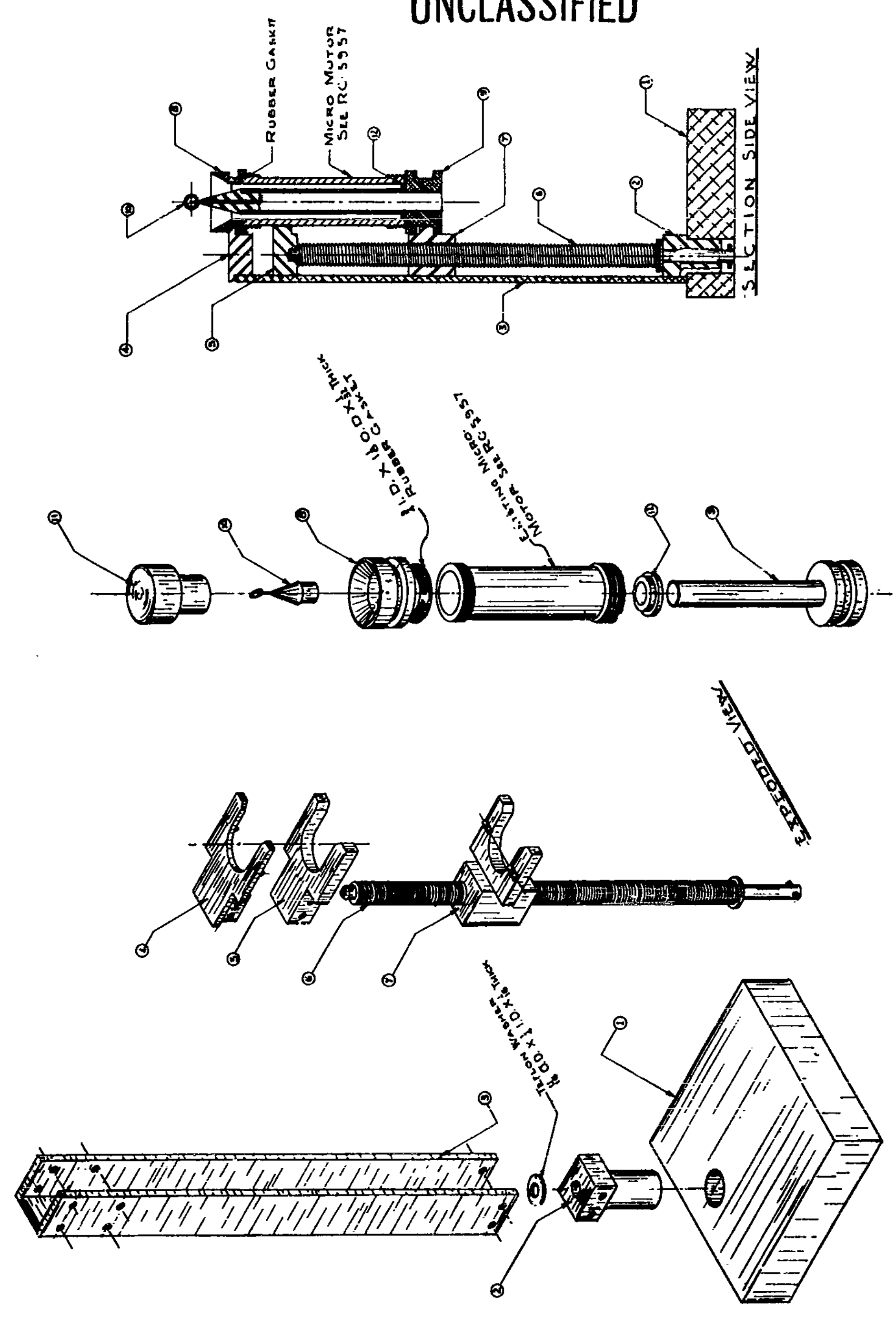

Fig. 15 Hardware for casting and dissassembling micromotors.

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Figure 16

Specific Impulse Data on SA-1

Motor[a] Configuration	Motor Size (gms. propellant)	No. of Shots	F^o 1000 lbf.-sec/lbm.	F^o 1000 ρ lbf.-sec/in^3
0.75 (C 0.5) 1.5	10	5	243.6	
0.75 (C 0.5) 2.5	20	5	247.5	
0.75 (C 0.5) 3.5	30	5	248.0	
2 (C 1.5) 4	160	2	249.8	
2 (C 1.5) 14.6	600	5[b]	253.4	16.6

(a) The first number in the designation is the grain O.D.; the second figure designates the grain geometry and I.D.; the third figure is the grain length. Thus, a 2(C 1.5) 4 motor has a 2 in. O.D., a 1.5 in. I.D. (cylindrical geometry), and a length of 4 inches.

(b) Two of the five shots were rejected because of excessive ignition delay.

Appendix I

Properties of SA-1 Batches

Batch No.	Initial[a] Viscosity	Curing rate[b] at Curing Temp.	(c) T_{75}	(d) E_{75}	Sp. G.[e]	Residual Monomer	Initiator	Curing Temp.
1001	8,000 cp. (est)	0.5%/min.@122°F	107 psi	35%	1.815	not obtained	0.7% AIBN[f]	120°F
1002	2,400 cp. @70°F	not obtained	131	15	1.81	not obtained	0.7	120
1003	10,800 @57	not obtained	102	60	1.81	0.5%	0.1	120
1004	7,200 @66	not obtained	96	70	1.81	0.3%	0.7	105
1005	9,200 @64	0.7%/min.	108	70	1.81	1.1%	0.1	120
1006	6,400 @60	0.4%/min.	123	40	1.81	1.9%	0.1	120
1008	10,400 @67	0.7%/min.	131	40	1.81	0.3%	0.1	120
1009	10,800	0.8%/min.	140	50	1.82	0.25	0.1	120
1010	9,000 @69	1.7%/min.	125	50	1.81	0.25	0.5% CDB[g]	120
1011	12,000 @72	2.8%/min.	123	35	1.81	0.2	0.5	120
1012	11,400 @84	-	-	-	-	-	-	(h)
1013	15,000 @77	-	-	-	-	-	-	(h)
1014	9,200 @73	2.7%/min.	200	80	1.815	0.00[illegible]	0.5% CDB	120
1015	9,800 @76	0.5%/min.@110°F	125	30	1.815	0.18	0.5	110
1016	3,200 @78	0.7%/min.	99	25	1.82	0.28	0.5	110
1017	5,200 @79	1.3%/min.	150	90	1.81	0.30	0.5	110
1018	10,800 @78	1.7%/min.				0.10	0.5	110
1019	9,600 @78	not obtained				0.20	0.5	110
1020	5,600 @85	0.9%/min.	83	20	1.80	0.55	0.5	110
1021	6,000 @82	not obtained				1.8	0.5	110

(a) Measured on a Brookfield Viscometer using spindle T-B at 5 RPM.
(b) Initial rate, measured dilatometrically.
(c) Maximum engineering stress, using R &H specimen number 2 and a strain rate of 2 in/min.
(d) Elongation at maximum stress.
(e) Determined by flotation method.
(f) Azo-isobutyronitrile.
(g) A 50% solution of 2,4-dichlorobenzoyl peroxide.
(h) Batches 1012 and 1013 were not cured since they were used in sensitivity tests on the uncured slurry.

Appendix II

Properties of Monomer Batches Used in Propellant

Monomer Batch No.	Propellant Batch No's.	% NFPA	%[a] X	Polymerization[b] Rate
4-450	1001	93.5	5.5	- -
49-348	1002	89.5	10.0	0.58
Blend A	1003, 1004, 1005	93.3	6.5	0.87
13	1006	96.1	2.4	0.94
42	1007	95.2	2.2	0.95
60	1008, 1010, 1011	90.3	6.4	0.97
57	1009	96.5	2.1	0.97
89	1012, 1013	94.4	3.0	0.98
90	1014	97.2	2.3	- -
91	1015, 1016, 1017, 1018, 1019	97.8	1.2	1.14
109	1020, 1021	98.2	0.8	1.07

(a) $CH_2 = CHCO_2\ CH_2C\ (=NF)\ CN$

(b) The polymerization rate of the monomer sample is measured at 60°C in benzene solution 1.13 molar with respect to monomer and 1.02×10^{-2} molar with respect to AIBN. The reported value is the ratio of the measured rate of the sample to the rate determined for a particular reference batch.

PREPARATION OF HAZARDOUS PROPELLANTS by the SLURRY PROCESS

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Around the middle of the year 1958 the Redstone Arsenal Research Division of Rohm & Haas Company became interested in the manufacture and evaluation of composite modified double base propellant. It was necessary to develop facilities and operating procedures for the manufacture of these propellants. The design of these facilities and the operating experience gained in the subsequent four years are discussed below with emphasis given to the safety aspects of the operation.

Composite double-base or plastisol propellants are high performance solid propellants with immediate or potential application in a number of military missiles. Figure 1 shows two plastisol propellant compositions that have been widely used at Rohm & Haas Co. These compositions employed a double-base casting powder with a nitrocellulose to nitroglycerin ratio of about 10 to 1 and a ratio of the plasticizer triethyleneglycol dinitrate to casting powder of about 2.5 to 1. Ammonium perchlorate and aluminum powder essentially completed the compositions. Some data on the sensitivity and stability of one of these compositions are shown in Figure 2. Some properties of the propellant which were important in influencing the design of the manufacturing process included the following: (1) a low viscosity in the uncured state, in the range of 2,000 to 50,000 cp measured on a Brookfield viscometer with spindle T-B at 5 rpm. The use of small (less than 10 microns) aluminum particles helped maintain the low viscosity; (2) a very low curing rate at temperatures below about 75°F and a rate at 120°F that effected a complete cure in less than 16 hours. The selection of type B "Fluid Ball" powder was a critical factor in obtaining the desired curing kinetics; (3) low sedimentation rates of the solid particles over a wide range of propellant compositions and oxidizer particle sizes. It was found that many compositions, some with viscosities as low as 3,000 cp., did not exhibit significant settling when maintained in the uncured state at ambient temperature for as long as 24 hours. In compositions where settling was a problem the technique of increasing the slurry viscosity by predissolving some of the casting powder in the TEGDN prior to the mixing operation was a simple and effective solution.

[1]This work was performed for U.S.Army Ordnance under Contract No. DA-01-021-ORD-12024.

Figure 1

Plastisol Propellant Ingredients and Typical Compositions

Ingredient	Wt. % in Composition 112	178
double base casting powder[a]	16.7	10.9
triethyleneglycol dinitrate	37.3	31.8
ammonium perchlorate[b]	30.0	35.3
aluminum[c]	15.0	21.0
resorcinol	1.0	1.0

(a) "Fluid Ball" casting powder, type B, containing approximately 90% nitrocellulose and 8% nitroglycerin.

(b) Coated with 1% tricalcium phosphate and ground to desired median particle size.

(c) Median particle size of about 8 microns.

Figure 2

Safety Information on a Typical Plastisol Composition

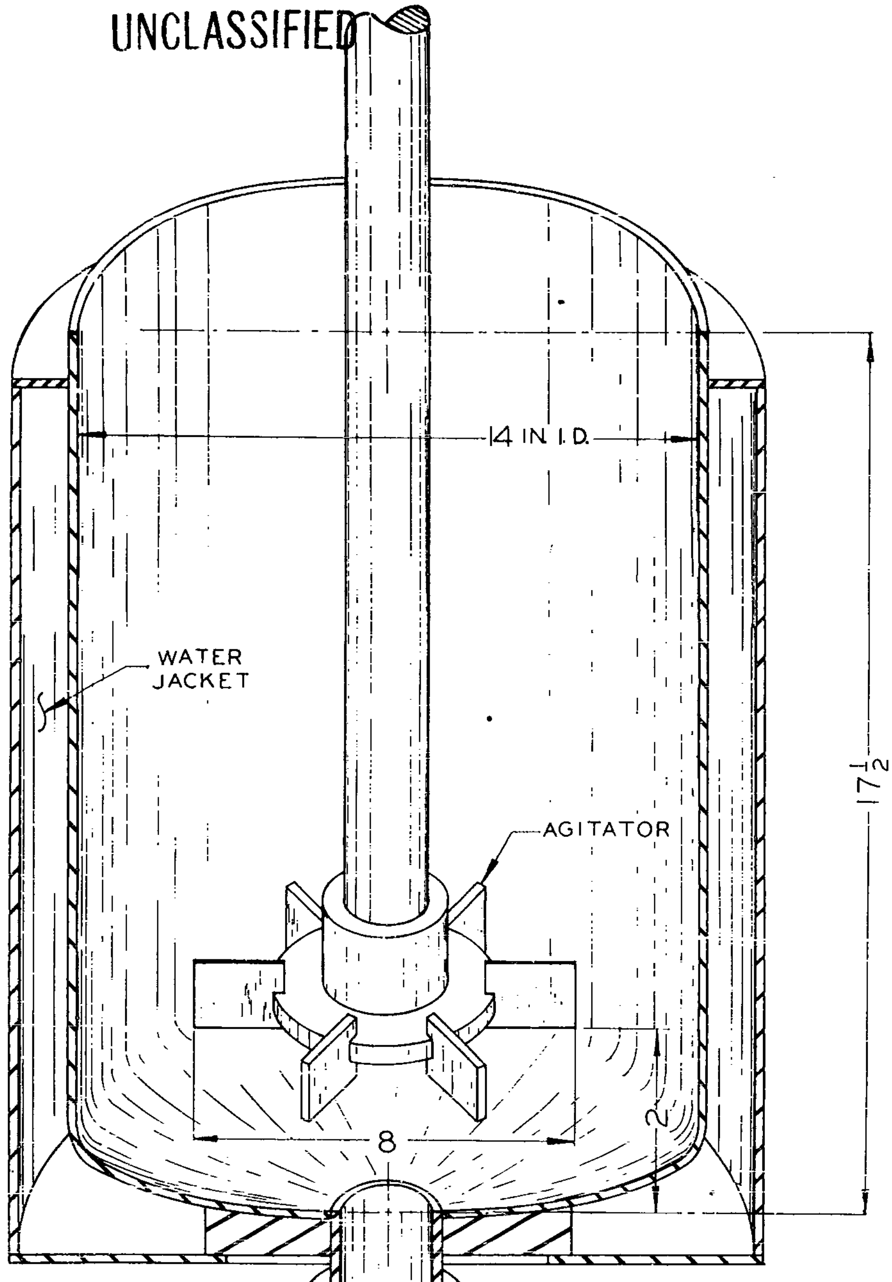
Composition	112_{CD}
Picatinny impact sensitivity - uncured propellant	9 kg.-in. - 50% level
Picatinny impact sensitivity - cured propellant	7 kg.-in. - 50% level
Card gap sensitivity - uncured propellant[a]	85 cards - 0.70 in.
Card gap sensitivity - cured propellant[a]	37 cards - 0.30 in.
Time to explosion[b]	65 seconds at 170°C 550 seconds at 150°C

(a) Acceptor charge was 1.05 inches diameter and confined in steel. Barrier material was cardboard.

(b) Tested in 22 caliber cartridges

The following philosophy and general guide lines were followed in the design of the equipment and process for the manufacture of plastisol propellants. (1) The confinement of explosive raw materials and of propellant in various stages of manufufacture was held to a minimum. To this end open top raw material charging vessels and propellant mixers were used. The propellant mixers were completely open top vessels except for loose-fitting, light weight plastic dust covers. (2) The opportunity for initiation of the raw materials or propellant was minimized. To accomplish this the process was designed to eliminate the use of such devices as screw feeders for oxidizer and explosive powders, mixing vessels which required bearings or seals in contact with or in the proximity of the propellant slurry, agitator blades with small clearances or high power input requirements, and pumps for transferring the propellant during the casting operation. (3) The exposure of personnel to hazardous operations was minimized. Remotely controlled operations were used for such steps as charging of hazardous raw materials to the mixer, agitation of the propellant slurry, deaeration, and motor curing and disassembly. These remote operations were controlled from areas located and barricaded to protect the personnel in them from injury due to blast pressure or shrapnel in event of a detonation of the propellant in process. The casting operation, which involved only the flow of propellant from one vessel to another under moderate pressure differentials, was carried out non-remotely. (4) Consistent with the first three criteria, the versatility of the facilities was kept at a maximum. Since the plastisol propellant program strongly emphasized development type operations, it was important that capability be established for handling a wide range of propellant compositions, batch sizes, and motor sizes and configurations. (5) Simplicity of both process and equipment design was emphasized wherever possible. The propellant properties of low viscosity, favorable curing kinetics, and low settling velocities mentioned above were particularly helpful in achieving this goal.

The heart of any propellant manufacturing process is the mixing operation. Three propellant mixer facilities having nominal capacities of 1 gal., 10 gals., and 100 gals. were designed and installed. The 10-gal. mixer, which was typical of all three mixers, is shown in Fig. 3. Important features of the mixer design were the unbaffled, jacketed, open top mixing vessel, the flush bottom valve, and the thermowell. The agitator design included a variable speed air motor drive and a single flat bladed turbine impeller with a diameter about half that of the mixing vessel, resulting in clearances of about three inches between the impeller blades and the mixer wall. Fig. 4 is an actual photograph of the 10 gal. mixer facility which shows, in addition to the mixer, some of the important features of the raw materials charging system. The TEGDN was pre-weighed, poured into an intermediate charging vessel above the mixer, and remotely discharged into the mixer by gravity. The solids ingredients were screened and weighed into appropriate polyethylene hoppers containing bottom discharge



TEN GALLON SLURRY MIXER

Fig. 3 Ten gallon turbine mixer.

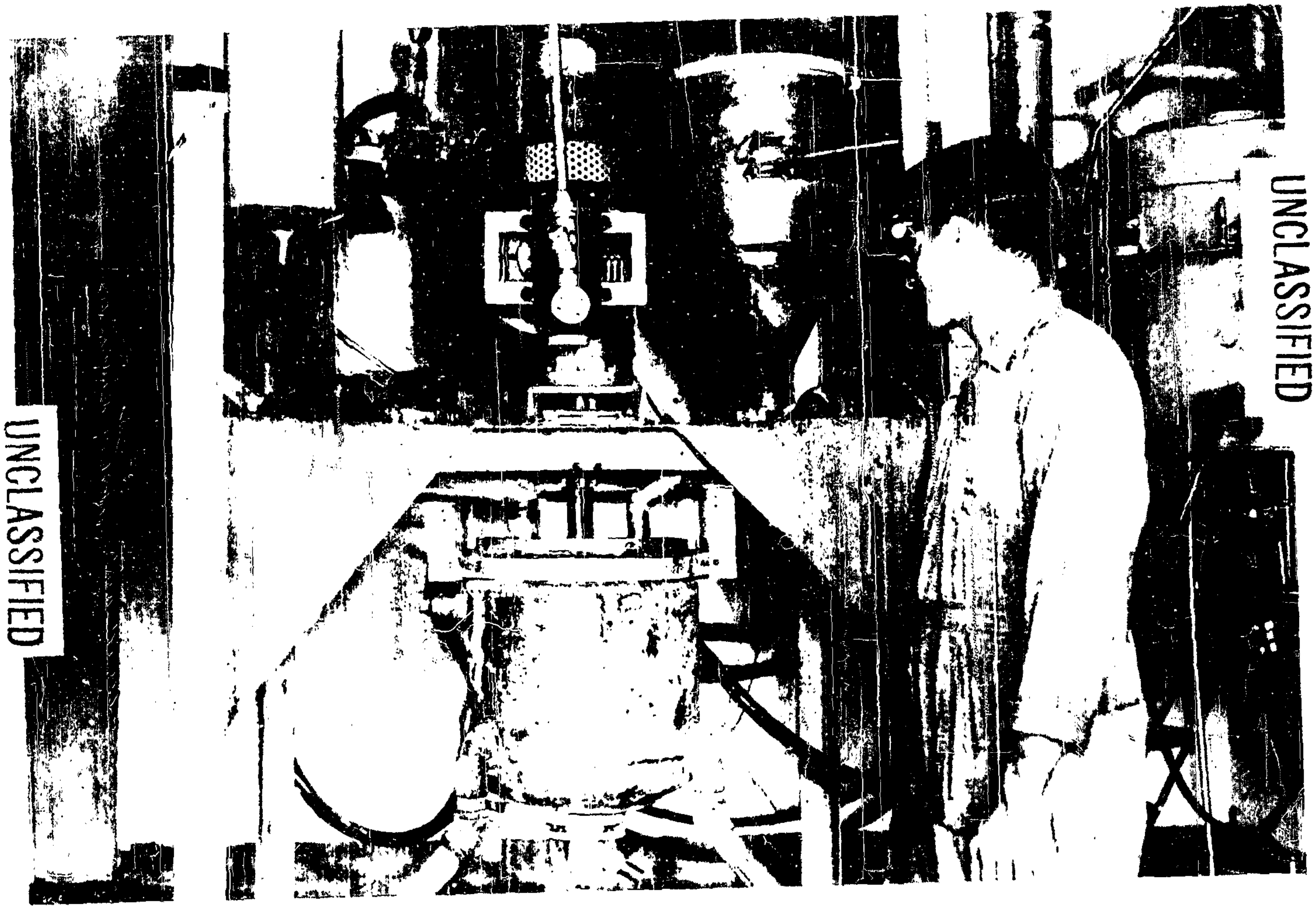


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Fig. 4
Photograph of Ten Gallon Mixer Facility

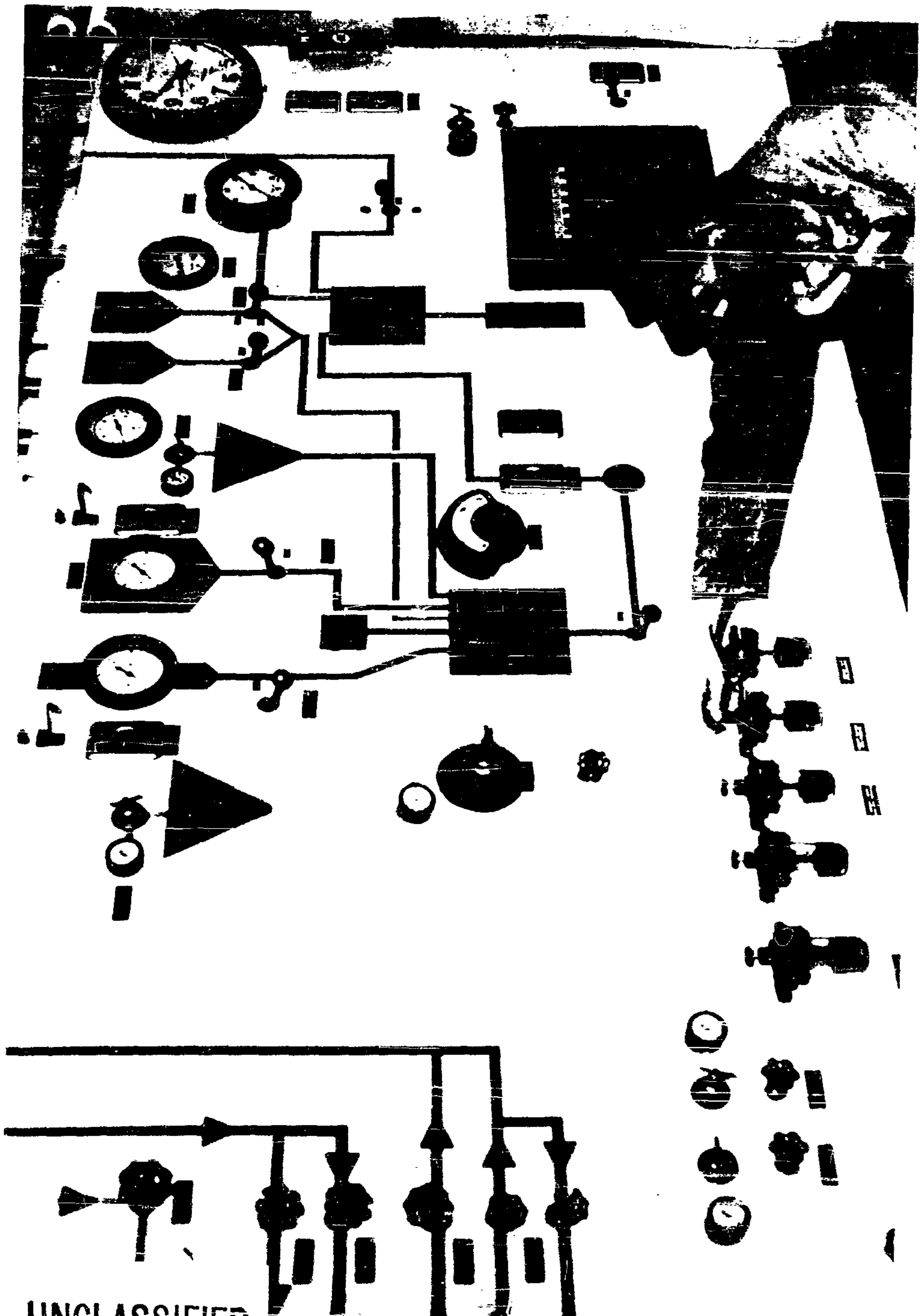


Fig. 5
Control Panel for Ten Gallon Mixer

openings equipped with removable metal plugs. These hoppers were then placed in the pneumatically vibrated metal charging vessels, the plugs were pulled remotely, and the materials were fed at essentially uniform rates through the outlets of the vibrating hoppers into the mixer. A ventilation hood for removal of any dust that escaped through the openings in the dust cover was positioned over the mixer to protect the working parts of the agitator drive from contamination with hazardous dusts. Figure 5 is a photograph of the control panel for the 10 gal. mixer.

Figure 6 shows a typical batch cycle for a full-sized batch in the 10-gal. mixer. Essential operations included charging of the TEGDN, charging of the double-base powder and aluminum powder while agitating, charging of the oxidizer while agitating, final mixing of the propellant slurry, slit deaeration, and casting. These operations were controlled remotely except for casting and visual inspection of the batch between operations.

A study of the importance of several variables in the mixing process led to the following conclusions: (1) The optimum mixer configuration consisted of a vessel with an L/D ratio of about unity and a single impeller about half the mixer diameter located near the bottom of the vessel. Higher L/D ratios reduced top to bottom turnover, thus decreasing the rate at which solids added at the top of the batch could be blended in uniformly. It was observed that a dual urbine arrangement actually interfered with the incorporation of the solids during the early part of the batch cycle when the upper impeller was not completely submerged. The presence of sidewall baffles in the mixing vessel was unnecessary and, indeed, harmful for the more viscous compositions since they tended to impede flow in the vessel. (2) The rate and uniformity of oxidizer addition were important mixing variables. If a certain critical rate was exceeded, the oxidizer tended to accumulate in a partially wetted state on the agitator and vessel surfaces and was difficult to incorporate into the batch. The magnitude of this critical rate depended upon a number of factors such as mixer size, agitator speed, batch viscosity, etc., but was usually in the range of 100 lbs./hr. to 500 lbs./hr. for the 10-gal. mixer. (3) The required mixing time after incorporation of all the solids into the batch increased with batch viscosity. For a viscosity of about 5,000 cp a mixing time of 5 min. was adequate, but mixing times in the neighborhood of 30 min. were required for viscosities around 50,000 cp. (4) The mixing variables of viscosity, agitator speed, and mixing time in some instances had a significant effect on the reproducibility of the mechanical properties of the cured propellant, as shown in Fig. 7.

The advantages of a turbine mixer diminish with increasing propellant viscosity due to higher power requirements, longer mixing times, and difficulties with solids incorporation caused by reduced flow in the mixer. Fig. 8 shows some of the mixing requirements for two widely

Figure 5

Typical Cycle for 100 Pound Batch

Operation	Conditions	Time Required
Preliminary operations		15 min.
Charge resorcinol	manually	1
Charge TEGDN	gravity feed	3
Agitate	300 fpm, 70-75°F	2
Charge NC, dAluminum	500 fpm, 70-75°F	10
Agitate	600 fpm, 70-75°F	2
Charge APC	700 fpm, 70-75°F	15
Agitate	800 fpm, 70-75°F	15
Deaerate	20mm mercury, 70-75°F	5
Cast	manually, atmospheric pressure and temp.	15
Clean up		10
Total		90-100 minutes

Figure 7

Effect of Mixing Variables on Reproducibility of Mechanical Properties

Variances of Tensile Strength for Three Factor Factorial Design[a]

	V_1			V_2			V_3		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
S_1	20.0	8.9	11.1	4.7	4.2	5.1	4.1	4.4	3.8
S_2	2.4	2.6	2.5	2.8	0.4	10.2	2.9	2.9	0.5

S_1 = 900 ft/min.; S_2 = 1150 ft/min.

V_1 = 10,000 cp.; V_2 = 25,000 cp.; V_3 = 60,000 cp.

T_1 = 10 minutes; T_2 = 20 minutes; T_3 = 30 minutes

(a) S was impeller blade tip speed; V was viscosity of slurry measured at 5 RPM with spindle T-B on Brookfield Viscometer; T was mixing time after addition of the oxidizer. Variances of tensile strength are in $(psi)^2$ with four degrees of freedom associated with each variance. Results are from eighteen batches made in random order in a two-pound capacity turbine mixer.

Figure 8

Effect of Viscosity on Mixing Requirements

for Ten Gallon Turbine Mixer

	Viscosity	
	10,000 cp.	100,000 cp.
Agitator Speed Required	450 ft./min.	900 ft./min.
Horsepower Required	0.4	4
Charging and Mixing Time	50 min.	120 min.

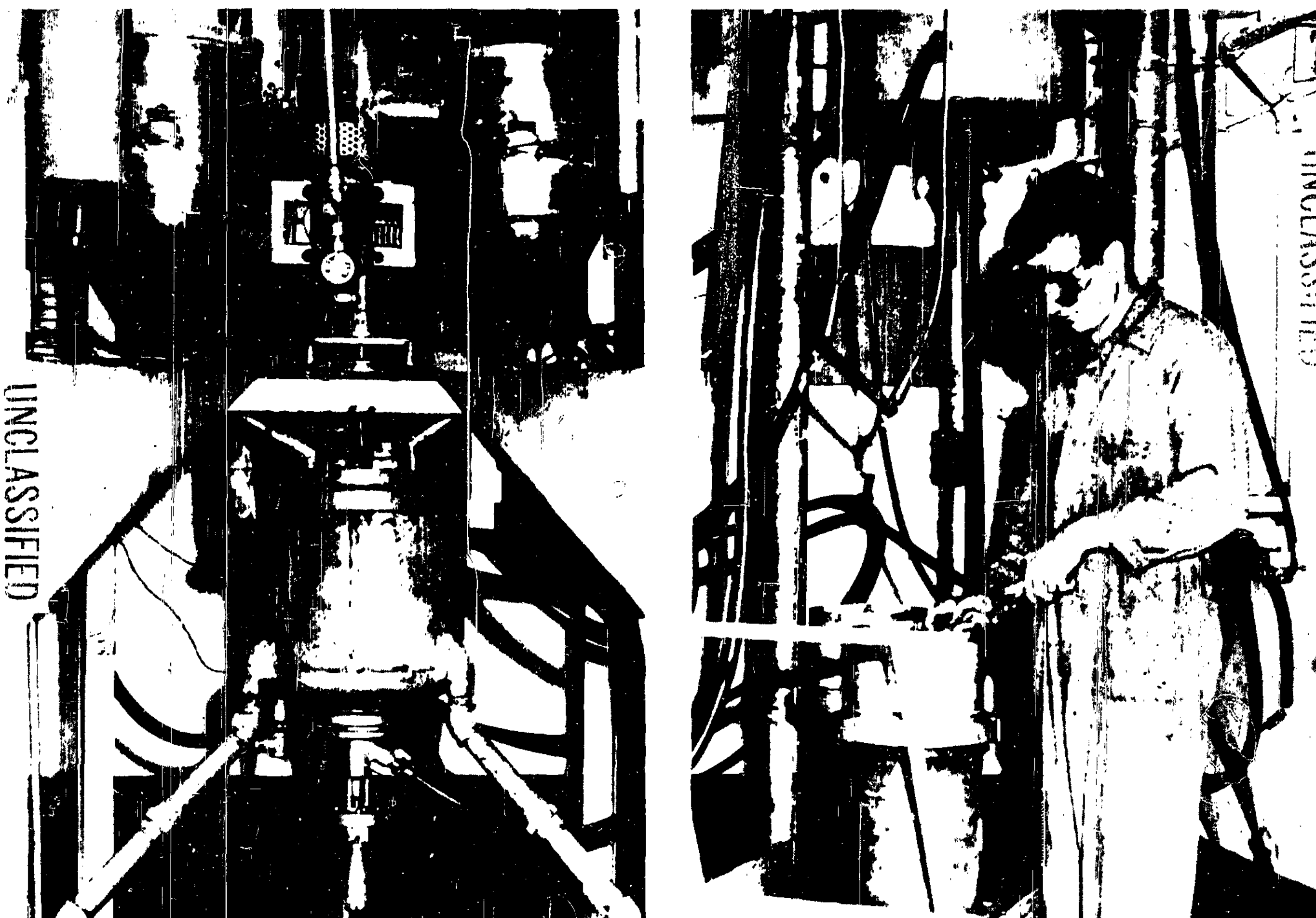


Fig. 9
Casting Plastisol Propellant

different propellant viscosities. The maximum viscosity for which a turbine agitator is effective depends greatly on the particular details of the operation and application being considered. For the particular case used as an illustration above, i.e., the mixing of plastisol propellant in a 10-gal. mixer, the upper viscosity limit was in the range of 75,000 to 100,000 cp. The limiting factor was the ability to remove the energy of mixing from the propellant slurry and thus maintain the temperature low enough to prevent further increase of the propellant viscosity due to the curing reaction.

The successful operation of the open top atmospheric mixer depended on the ability to effectively deaerate the propellant at some later stage of processing. Using the slit deaeration technique effective deaeration was obtained for an extremely wide range of slit sizes, propellant viscosities, deaeration rates, and vacuum levels. Deaeration was evaluated by microscopic examination of samples of cured propellant and by routine measurements of propellant densities. Microscopic examination of 40 micron thick slices of cured propellant revealed that slit deaeration reduced the frequency of voids from about 100/cm^2 to zero for a propellant of about 50,000 cp. viscosity. The batch-to-batch standard deviation of densities for a given composition was less than 0.2% and the mean value of the density was equal to or slightly greater than the density calculated from the specific gravities of the individual components.

Casting was carried out by direct manual control using either pressure or gravity to induce flow of the propellant. Both top and bottom casting techniques were employed, and casting at atmospheric pressure did not result in entrapment of air in the propellant grains. Fig. 9 is a photograph of a typical casting operation. The record of motor production for two specific development programs in which motors were inspected by radiographic techniques is shown in Fig. 10. Although both motors had complicated configurations resulting in unfavorable flow conditions in the motors, not one single motor was rejected because of air trapped in the propellant grains during casting. Some effort was expended on development of hardware that would allow remote disassembly of the casting fixtures and eliminate the trimming operation. A design that successfully accomplished these purposes for a 6 -lb. quality control test motor is shown in Fig. 11.

Propellant manufactured according to the above scheme was found to have uniformly high quality. Fig. 12 shows the overall reproducibility of two important interior ballistic parameters for one particular plastisol composition as measured in a 6 -lb. test motor. Using the process described approximately 800 batches, varying in size from 2 to 1,000 lbs. and containing a total of 75,000 lbs. of 53 plastisol compositions, were made without any accident or known near-accident occurring in the manufacturing process. It is believed that a

Figure 10

Record of Motor Production for Missile A and Nike Zeus Programs

Motor description	No. of Motors	Fraction of Motors in Class A[1]	B[2]	C[3]
Missile A	211	79%	12	9
1/5 scale Nike Zeus booster	71	93	7	0

[1]No flaws found in X-ray or visual inspection expected to be detectable on pressure or thrust traces.

[2]Flaws found in X-ray or visual inspection which were expected to be detectable in traces but which should not prevent successful firing.

[3]Flaws found in X-ray or visual inspection which were expected to prevent successful firing.

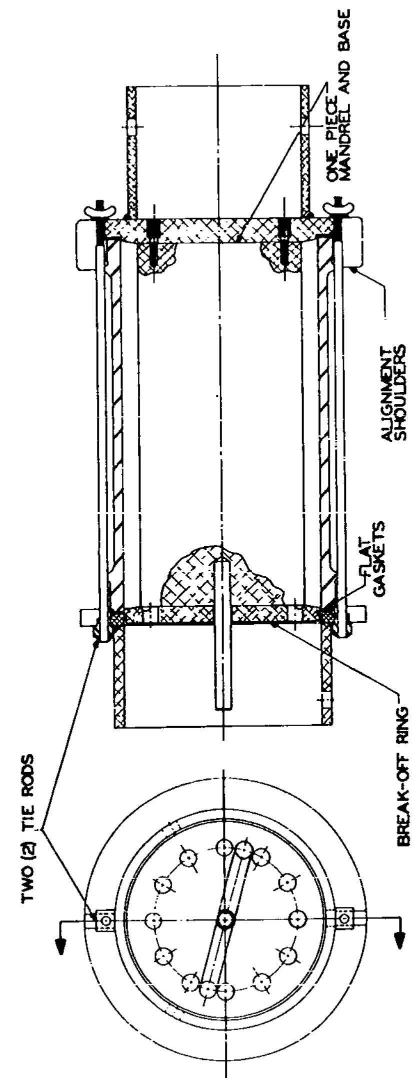


Fig. 11 Fixtures for six pound test motor.

Figure 12

Reproducibility of Ballistic Properties

of 112_{cb}

	Average	Standard Deviation
Specific impulse - 1000 psi	245 $\frac{\text{lbf.-sec.}}{\text{lbm.}}$	0.3%
Burning rate - $77^{o}F$, 1000 psi	0.69 in/sec	3%

significant part of the credit for this successful experience is due to the compliance with the design guide lines outlined earlier, viz., the minimization of confinement of explosive materials in process, the minimization of opportunity for initiation of explosive materials in process, the minimization of exposure of personnel to processing hazards, and, perhaps most important of all, the emphasis on simplicity of design and operation of the process.

Dr. Johnson: Slurry casting is a technique of course that many companies have been investigating for three or four years. Rohm & Haas, I think, has done an excellent job. In the Navy our work has been confined to the laboratories of Hercules and the Naval Propellant Plant. The families of propellants that the Navy has been investigating are more energetic than those that Rohm & Haas had and the hazard is greater. We've had a rather dismal experience with them so far. We've had two bad accidents at ABL, a fatal accident at NPP in which five people were killed and Hercules Bacchus had a bad explosion all with slurry casting. These were formulations in which the plasticizer was nitroglycerin, not TEGEN and in which part of the oxidizer had been replaced by HMX. This is all classified of course. These, however, are propellants that are going into large DOD motors. The ABL formulation is going into Polaris second stage, the Hercules Bacchus Works is going into Minuteman third stage. So from a DOD standpoint we are very much interested in getting the bugs out of slurry casting and I think the Rohm & Haas work has demonstrated that if its properly planned and carried out it can be, but I don't think they've faced up to the most hazardous grade of propellants that we would like to use it on. Since our accidents, we've made a rather intensive effort in the Navy labs to get the bugs out of it and I understand that Hercules Bacchus has devised a new mixer which is quite different from yours and shows a great deal of promise. I just wondered if you'd seen that nor if anyone from Hercules would want to comment on it.

Mr. Parrott: The sweetie barrel?

Dr. Johnson: Yes.

Mr. Parrott: I have not seen it, but I have heard reports of it.

Dr. Johnson: It looks like what you want to do if you want to do slurry casting, is buy up a bunch of surplus cement mixers or something like that. The deaeration step still does not have all the bugs out of it. We found out that in the types of formulations used in the Navy and Air Force propellant programs, the continuous liquid phase in this slurry testing operation is frequently 90% nitroglycerin. That's a very dangerous liquid as anybody can guess off-hand, particularly if you have HMX slurried in it. You have to be very careful with it and

during the deaeration step, when you pull a vacuum on it and you have now suddenly filled it with void to partially evacuate it, it's hazards drastically change and one must be real careful in designing your deaeration step to get around these hazards. I just wanted to pass this on because we have a lot of faith in slurry casting, we think the bugs can be gotten out of it. But it isn't all a bed of roses as Rohm & Haas has indicated and partly because they haven't really faced the most hazardous type propellants that we'd like to use slurry casting on.

Mr. Parrott: What you say about the propellant compositions we dealt with is certainly true. However, correct me if I'm wrong, my understanding of the incidents you talked about is that essentially every one of them occurred during a vacuum mixing operation. And we have eliminated that type of operation from our process and it is our opinion that were we manufacturing these HMX-NG containing formulations right now and we are beginning to, that we would use essentially the process I described. As for the sweetie barrel or concrete type mixer, I think it does have some of the same advantages and disadvantages of the impeller type, low energy input and no moving parts in contact, but it does seem to me that it is simpler to turn a shaft inside the mixer than to rotate these higher mixing containers which is what the sweetie barrel process involves.

Mr. Settles: Dr. Johnson, I kind of resent that label of cement mixer that you put on it, although by and large that's probably right. It isn't my intent to give a brand new paper right here in the middle of this thing and the reason we're not talking about the sweetie barrel or the tin type (ed. ??) mixer, whatever you want to label it at this particular seminar, is that we're still in the process of finding out just what it's characteristics are. This time next year I would hope that we would be able to come back to you with something more definite than we have available at the present time, however, it does look hopeful and it looks hopeful especially for the processing of sensitive ingredients and particularly friction sensitive ingredients and the reason it does is that you remove all mechanical agitation inside of the mixer. This is simply a barrel, if you want to call it that, a cement mixer if you want to be a bit more crude, but it's a cement mixer of a particular design and of special materials and you're particularly concerned that this cement mixer doesn't have any cracks in it where metal can flex against metal as it rotates and also it is cantilevered so your structural considerations are of appreciable concern. If you can successfully take care of these structural considerations and guarantee that no cracks are going to develop in this barrel as you use it, then you have the advantage of no mechanical agitation inside the barrel at all. Furthermore we have found that we can successfully process viscosities we think of up to 200,000 centipoise. You don't get a mechanical shearing action inside of this mixer, however, you do

get the shearing action that is inherent when a material tears away from itself as this barrel rotates at approximately 5 to 10 to 15 RPM. It looks real good from the standpoint of processing friction sensitive ingredients. We'll be able to tell you more about it this time next year, I hope, and be real conclusive about our findings.

TECHNIQUES USED IN HANDLING FIRST STAGE OF THE MINUTEMAN MISSILE

by
R. E. Keating
Wasatch Division
Thiokol Chemical Corporation

It's a great pleasure to give this paper on behalf of Mr. H F. McQueen who was unable to attend this seminar.

In the missile industry, the handling of large propulsion units during manufacture is of such paramount importance that no one can expect to stay in business without sound techniques. With the advent of the space programs, the large boosters provide the urgency for continued improvement. While the handling of heavy objects is not a new art, the methods for handling thin shells loaded with high energy solid propellant, are underdeveloped for rocket motors over the one hundred (100) ton class.

The large boosters for interplanetary travel will be gigantic and several million pound motors can be anticipated. Even with segmented motors, clustered to form the various stages, the segments will be large to increase reliability. To handle these large motors or segments, it will require experience both in processing and equipment design. We believe that by expanding the techniques used for the First Stage of the MINUTEMAN missile, along with new techniques, that these motors can be manufactured economically, safely, and with high reliability.

The processing of the MINUTEMAN's first stage begins with the receipt of the case from the vendor, Slide 1. The case arrives in its pressurized, dehumidified shipping container. The case and container are removed from the vehicle using an overhead crane and rectangular lifting arrangement. Slide 2. The pressure is then released in the container, the cover removed, and the same lifting arrangement is attached to the tie-down bands. The motor case is moved from container onto chocks.

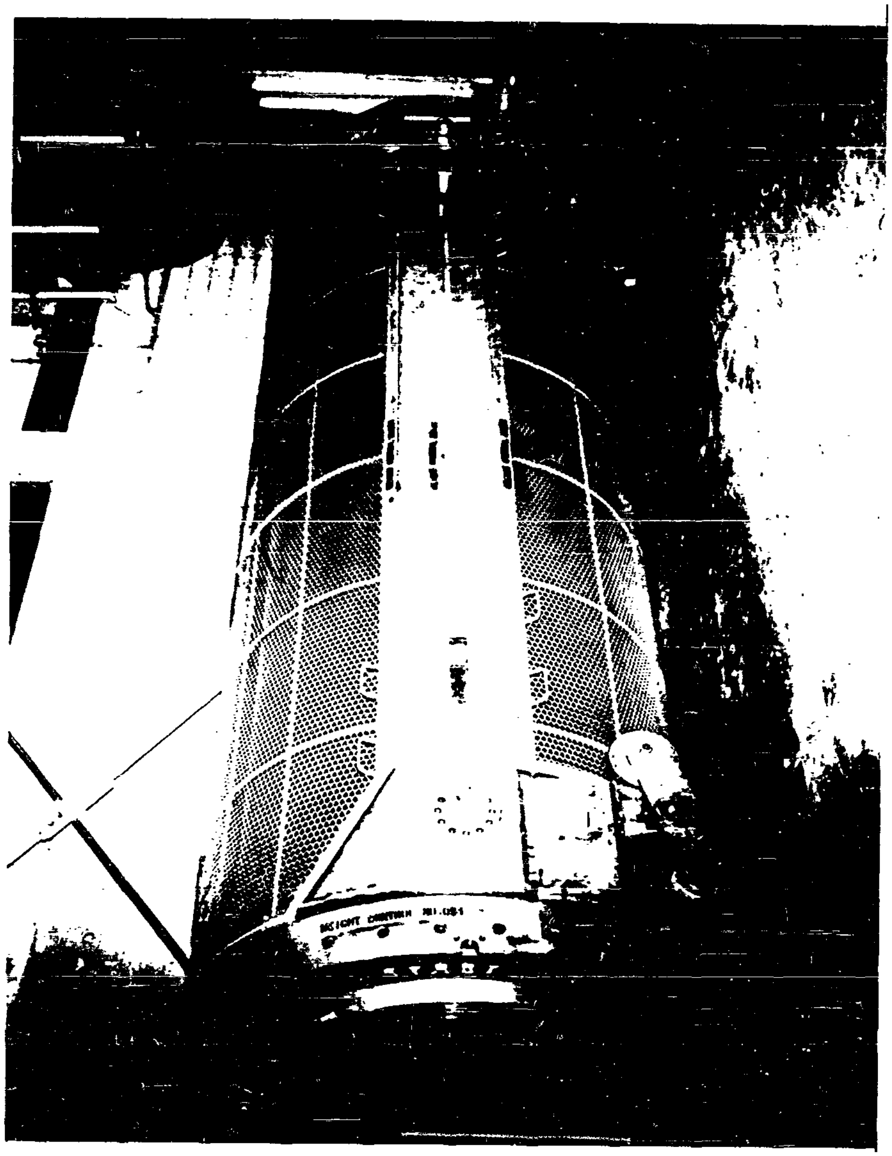
Slide 3 - the handling harness is next installed on the case. The main design features of the handling harness are:

1. It is rugged, easy to install and use by semi-skilled personnel.

2. It is reuseable and similar to conventional equipment being compatible with common carriers.

Slide 1

Slide 2



Slide 3

3. The large rings attached to both forward and aft skirts have rounding jacks which are used to round the case. The rings will then keep the case round throughout processing.

4. The heavy side beams transfer the load equally between the rings.

5. The trunnions located on both ends of the side beams provide the lifting points.

6. The "V" grooved wheels allow rail transfer for horizontal movement.

7. The protective screen cover offers adequate case protection.

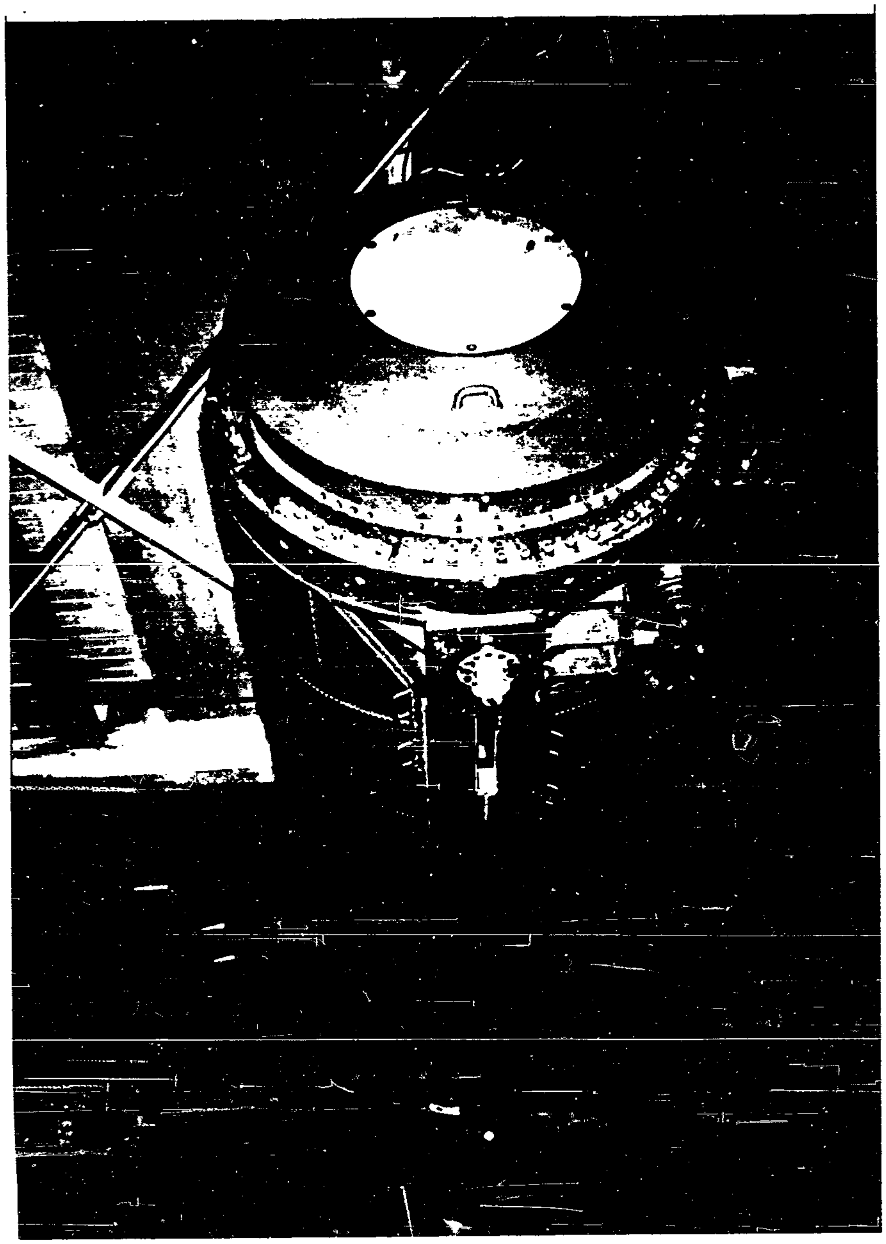
8. The forward dome is used both for protection and as part of the propellant casting stand.

Slide 4 - using this harness, the motor can be handled safely and it provides ample support to prevent bending moments of harmful amplitude in the case. The harness was also designed to be used for flight restraint during static test firing. During casting and finishing operations the harness is secured to stands which will restrain flight, if preignition occurs.

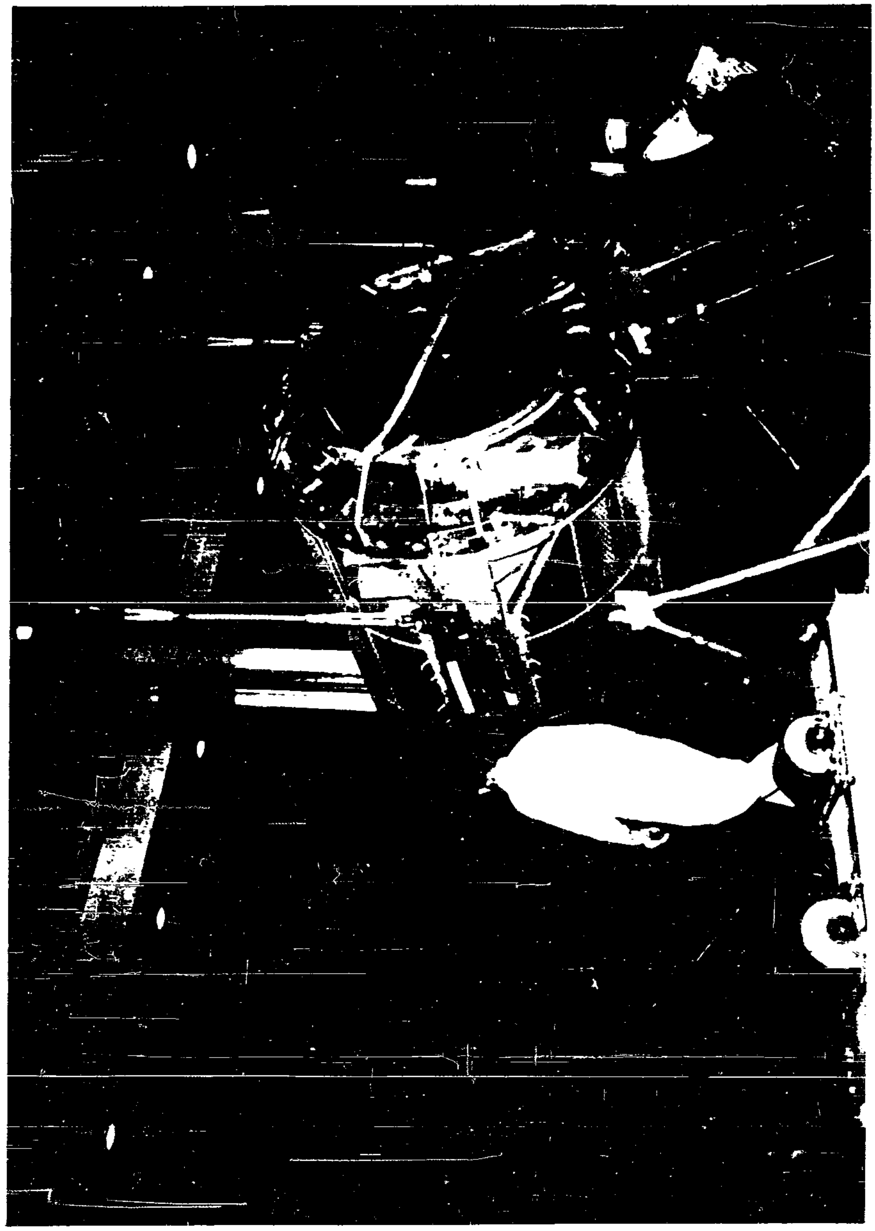
Slide 5 - the case is moved onto breakover stands using the horizontal lifting arrangement and crane. The horizontal lifting arrangement is removed and the vertical lifting beam is attached to the two (2) aft trunnions. The case is moved into a vertical position using a pivoting action on the stands.

Slide 6 - The crane moves the case in a vertical position over the degreasing pit where the case is spray degreased. After degreasing, the crane again moves the case back to the breakover stands and the case is placed back into a horizontal position by reversing the steps. The case is then placed on a rotating dolly using the horizontal lifting arrangement. On the rotating dolly, the internal insulation is installed. The interior is hand degreased and the case is again moved to the breakover stand and placed in a vertical position. The crane then moves the case into a lining pit and it is secured onto a vertical stand.

Slide 7 - after lining, the crane moves the case onto a handling carriage. The handling carriage fits a standard semi-tractor and is designed to transport the motor in a horizontal position. The carriage features four (4) trunnion supports with electrically operated jacks to raise and lower the motor. At the four (4) corners are leveling support jacks for stability during loading and unloading operations.



Slide 4



Slide 5

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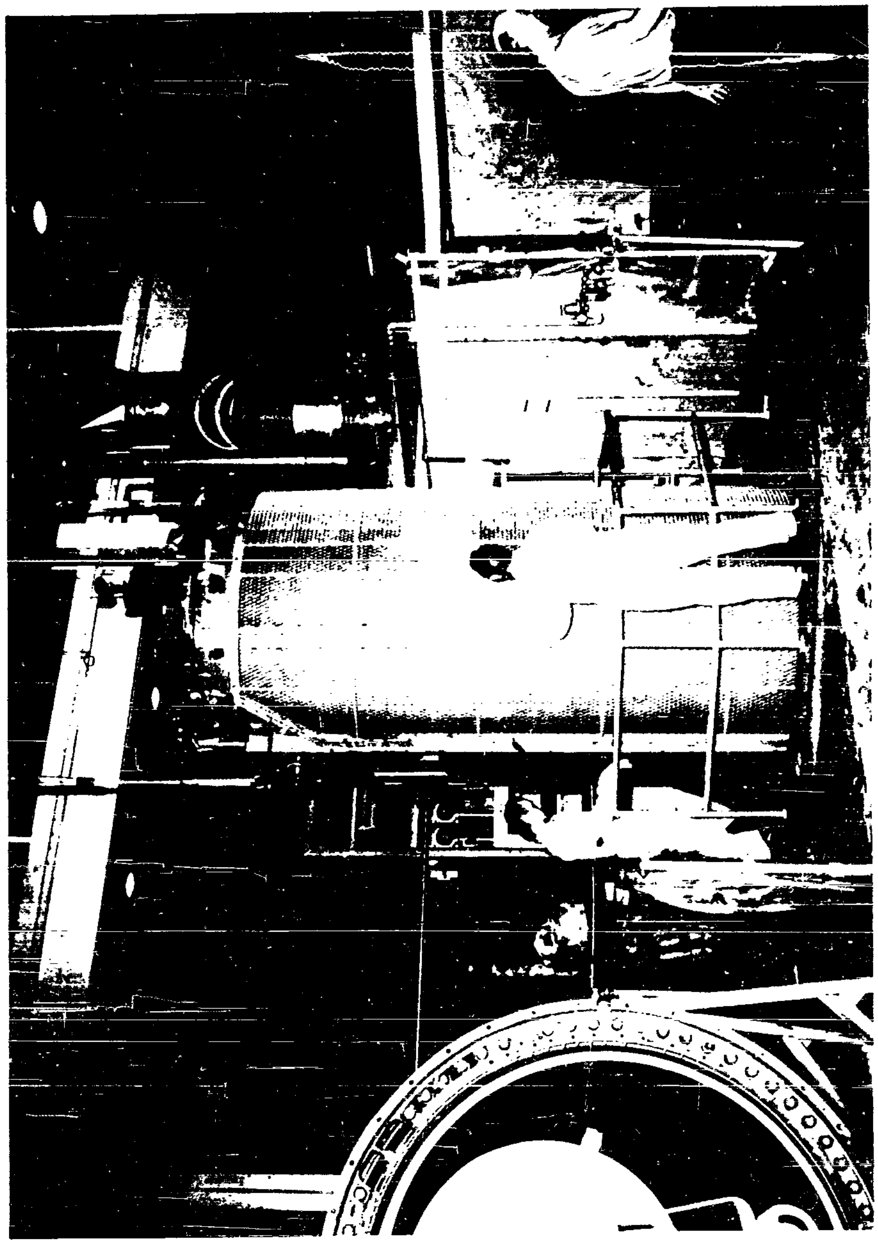

Slide 6

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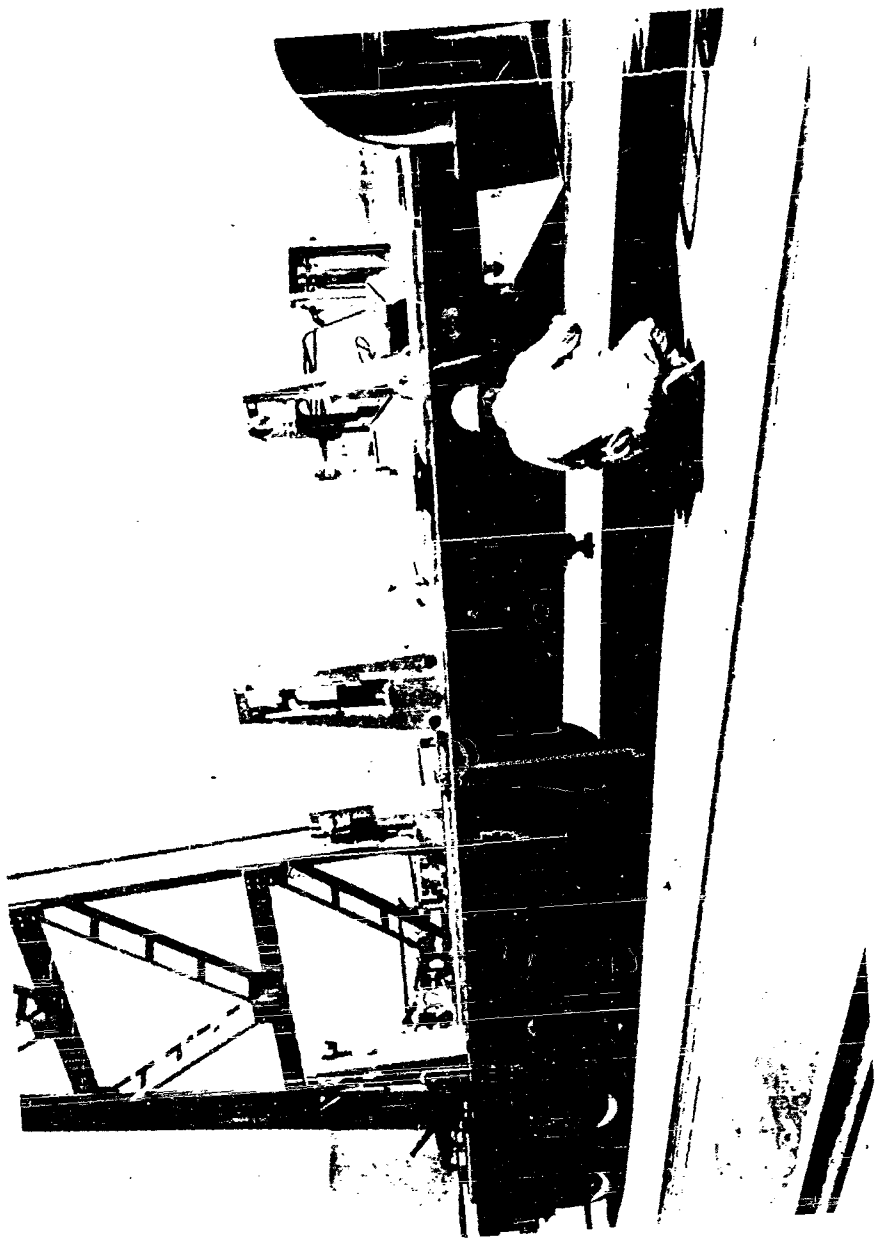

Slide 7

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The carriage is equipped with a set of v-grooved rails to match the v-grooved wheels on the handling harness.

To position the motor case onto the carriage with the crane while the motor is in a vertical position, the forward trunnions are lowered and secured in the forward trunnion supports on the carriage. The crane then pivots the aft trunnions down onto the rear supports.

Slide 8 - the insulated and lined case is transported on the handling carriage to the casting pits.

At the Research and Development Plant, we developed a concept of underground pit processing. This is the reverse of an assembly line. Instead of the product flowing through a sequence of stations for various operations, the product is stationary and the stations flow relative to it. In the manufacture of this motor, the pit processing has reduced the handling and increased safety considerably. The processing pits are large rectangular open top pits with reinforced cement sides with stands situated in the bottom. They are situated in rows between a rail system. A mobile gantry crane moves along the rails to have access to all the pits. Propellant casting buildings and finishing buildings are also mounted on the rails and are easily towed from one pit to the other. It is easier and simpler to move these buildings along the rails to perform the various operations on the motor than move the motor in and out of the buildings. For propellant curing, a cover is placed over the pit. A heating unit with air movers converts the pit into a oven for accelerated cure. The motors are secured in the pits and all working personnel are at the top level providing maximum safety. The entire processing of the motor could be accomplished in the pit; however, the motor is brought out for radiographic inspection, and center of gravity determinations. The gantry crane is used for installing and removing the motor from the pit.

Slides 9, 10, 11 and 12 - upon arrival at the pit, the handling carriage is backed in under the gantry crane. The crane with a vertical lifting beam attached is secured to the aft trunnions on the harness. The crane then pivots the motor to a vertical position on the forward trunnions. The trunnions are released from the supports on the carriage and motor lifted free. The crane then positions the motor over the pit and lowers it through the opening in the pit grating head end down onto the stand secured in the bottom. The case is then secured onto the stand. The core or mandrel is installed in the motor case.

The casting building is rolled over the pit and secured. The case is next preheated and cast with propellant. The casting building is rolled from the pit. The pit cover is then placed over the pit and the propellant cured. Upon completion of the cure and a cool-down period, the core is popped loose with a hydraulic arrangement and removed with the gantry crane. The aft grain is cut to the proper

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Slide 8

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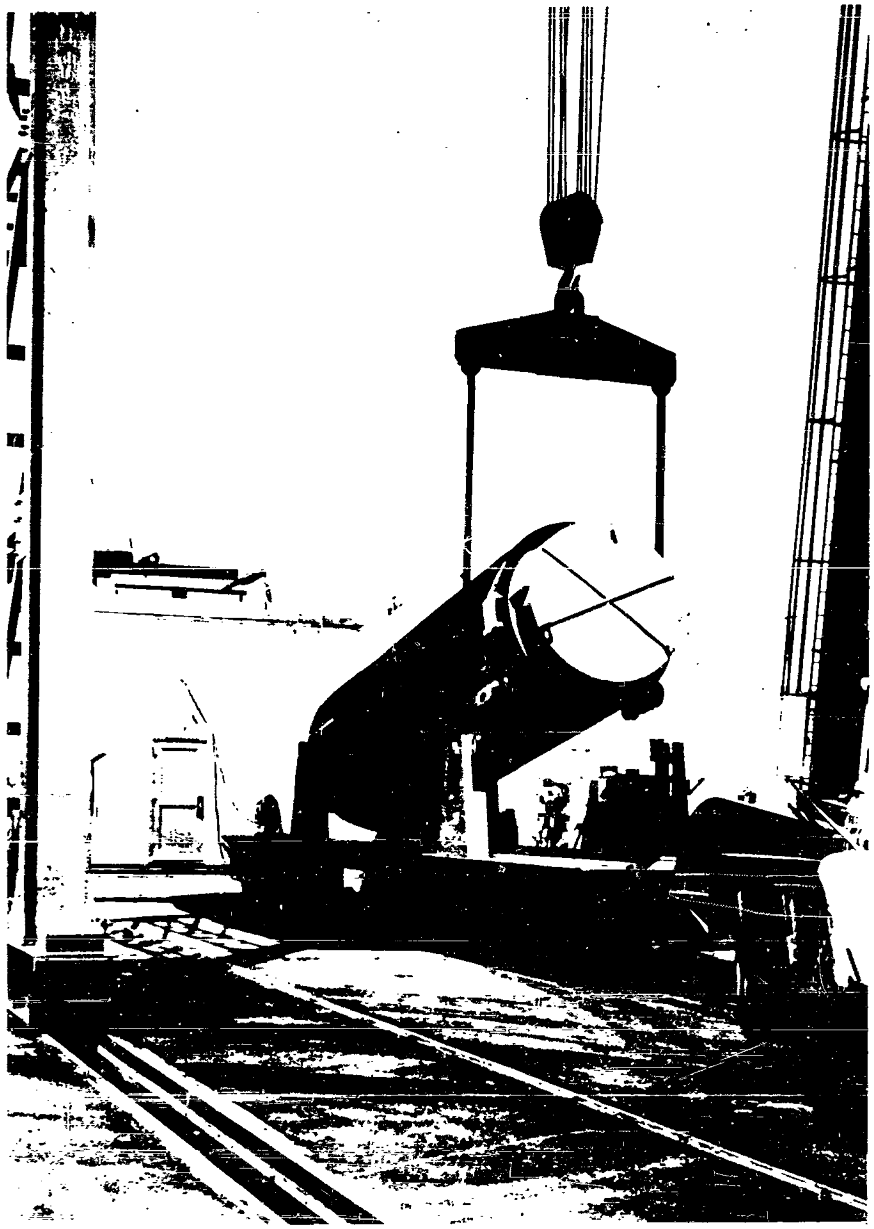
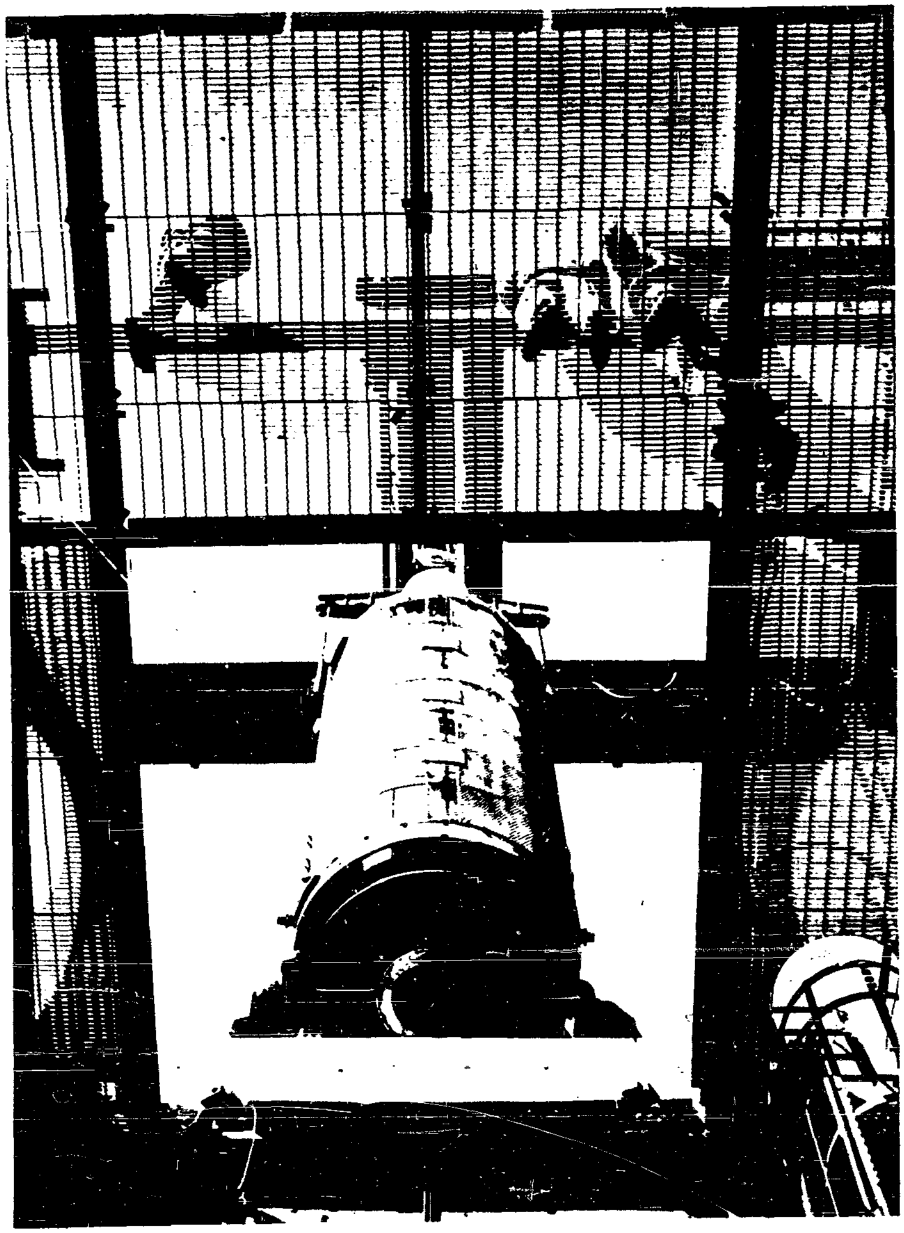
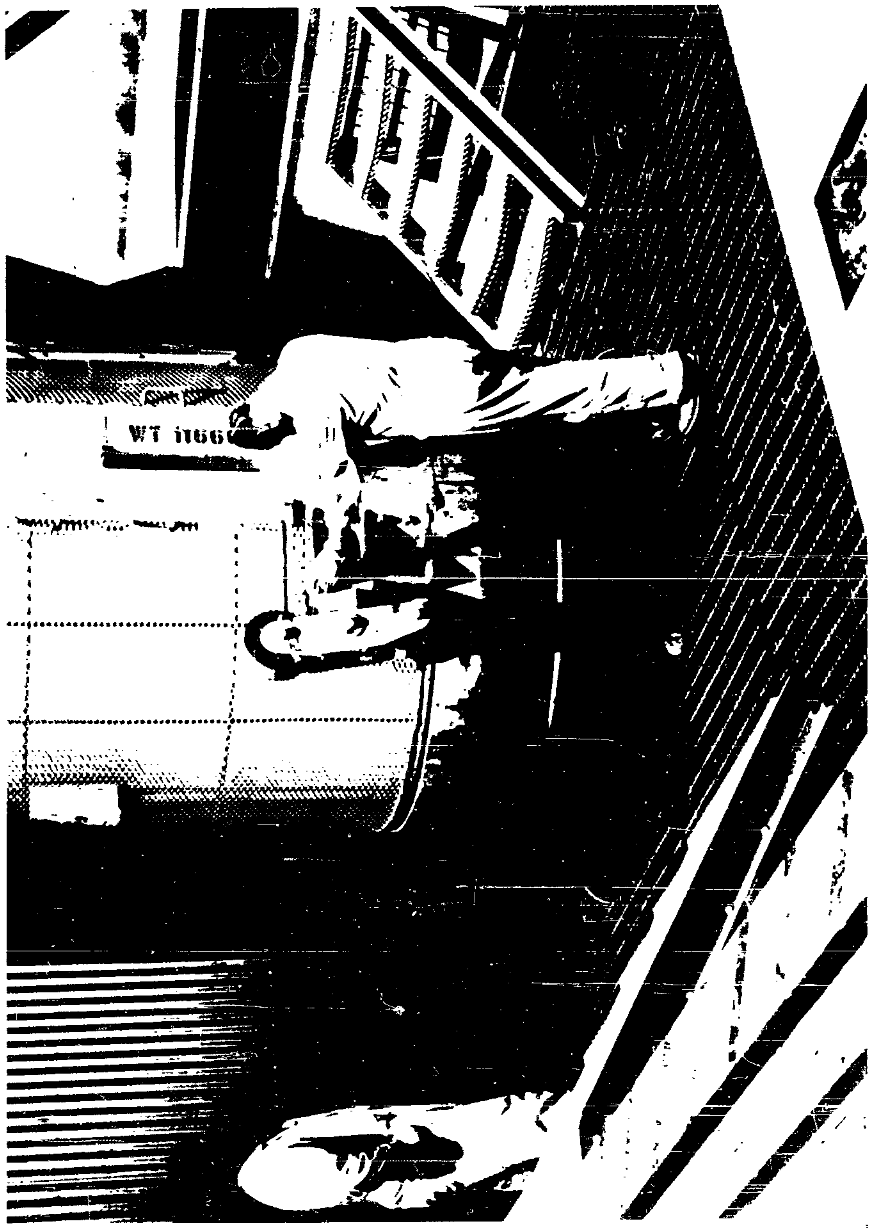


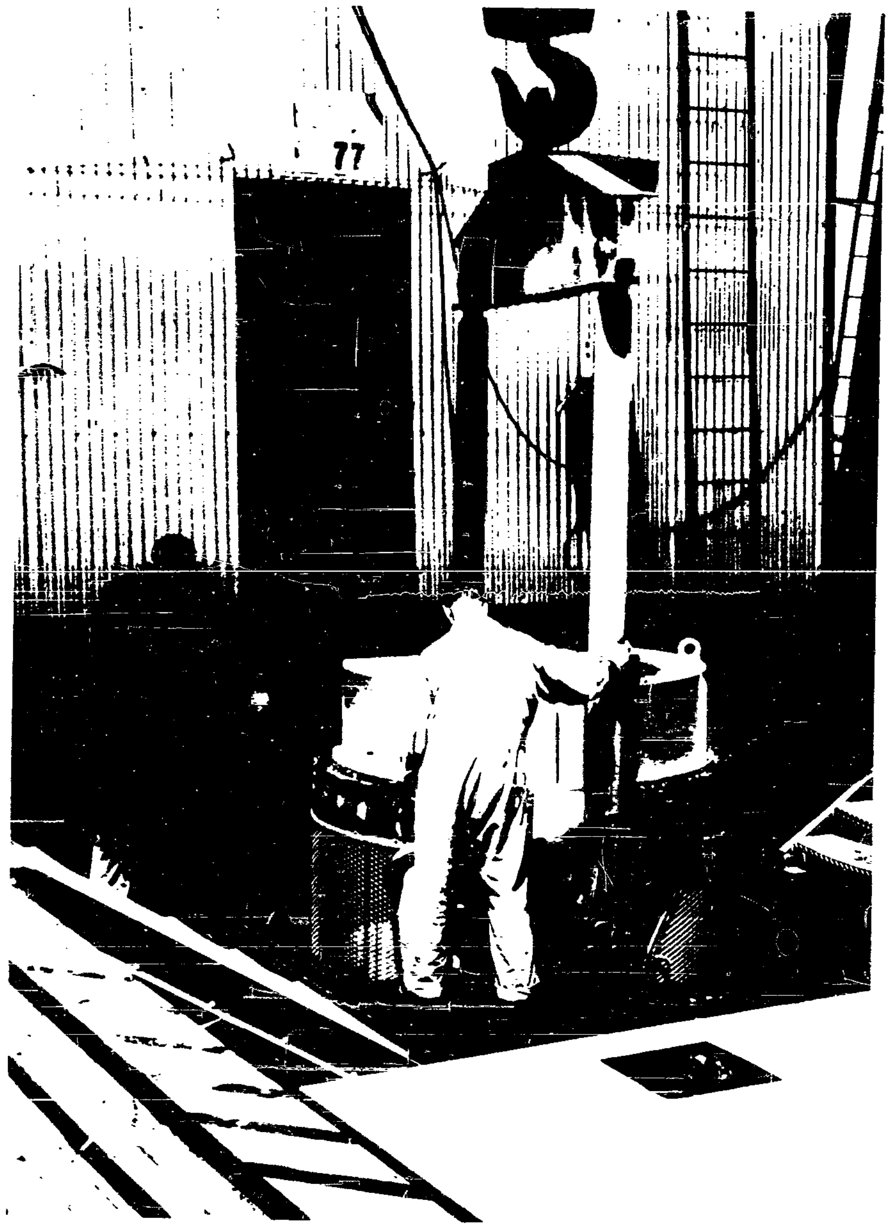
Slide 9



Slide 10



Slide 11



Slide 12

configuration remotely with an air driven cutting machine. An aft cover is placed over the loaded motor and the gantry crane with a vertical lifting beam removes the motor and places it back onto the handling carriage. The same procedure is followed as with the empty case. The motor is transported from the pit to the radiographic building. This building is equipped with a rail system and the handling carriage is backed up to the building, the rails on the carriage are aligned and leveled with the rails of the building, a transfer bridge placed between the rails and the motor is dual winched into the building. The winch in the building moves the motor into the building while the winch on the carriage controls erratic movement - slides 13, 14, 15, 16, and 17.

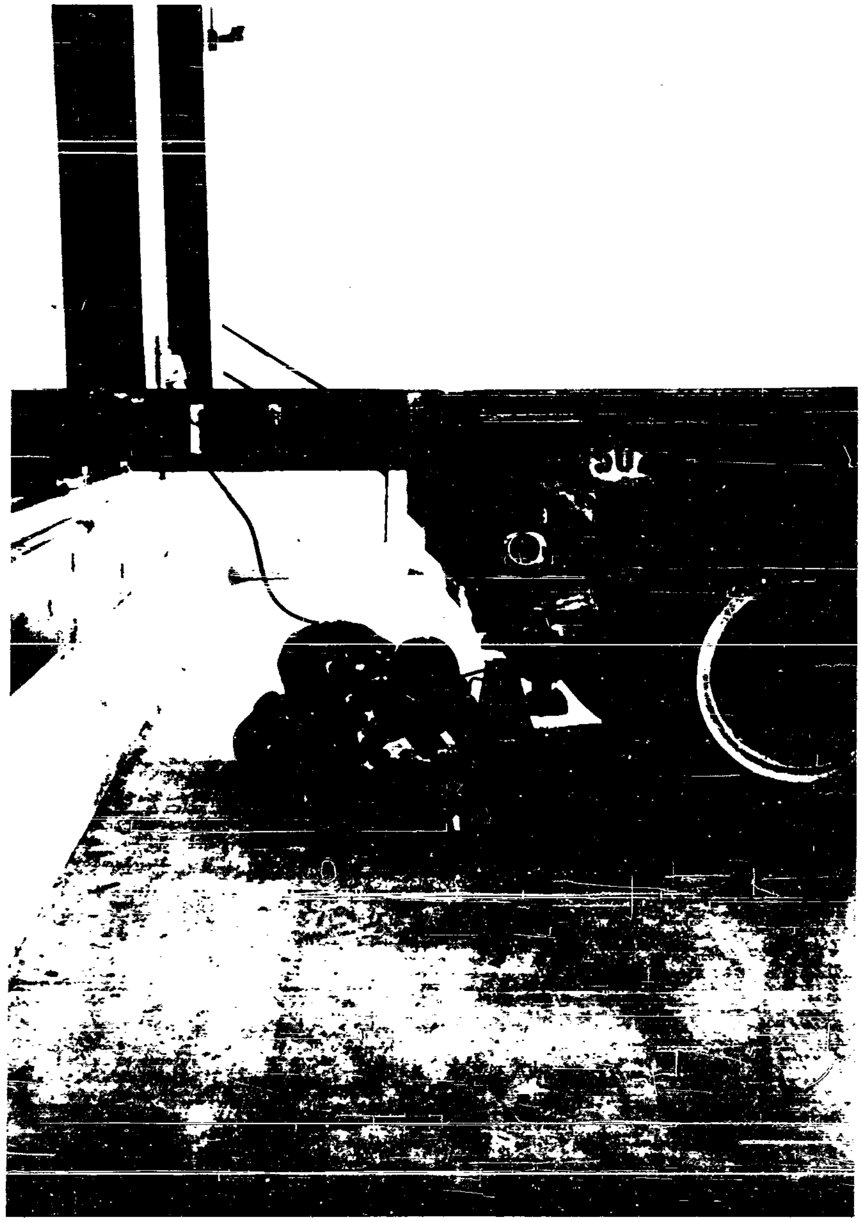
In the radiographic inspection building, the motor is lifted in the horizontal position using a horizontal lifting arrangement, as in case preparation, onto a rotating dolly. On this dolly, the handling harness is removed and the motor inspected for propellant defects. The harness is reinstalled and the motor is lifted back onto the rail system. The motor is then rolled back onto the handling carriage using the same horizontal roll method. The motor is again transported back to one of the pits and installed into the pit as before. The motor finishing building is rolled over the pit and secured in place. Aft closure and nozzle installation is accomplished at this time. The motor is again removed from the pit and placed on the handling carriage where it is transported to the weight and center of gravity determination building. The Weight and C.G. building utilizes a rail system and handling is accomplished by the horizontal roll method. From this point on, all handling is accomplished by the horizontal position on rails.

Slide 18 - for static testing, the forward casting stand adapter is replaced with the thrust adapter. Static testing is accomplished in both the horizontal and vertical position. For horizontal testing, the motor is dual winched onto the test stand utilizing the v-grooved wheels and rails.

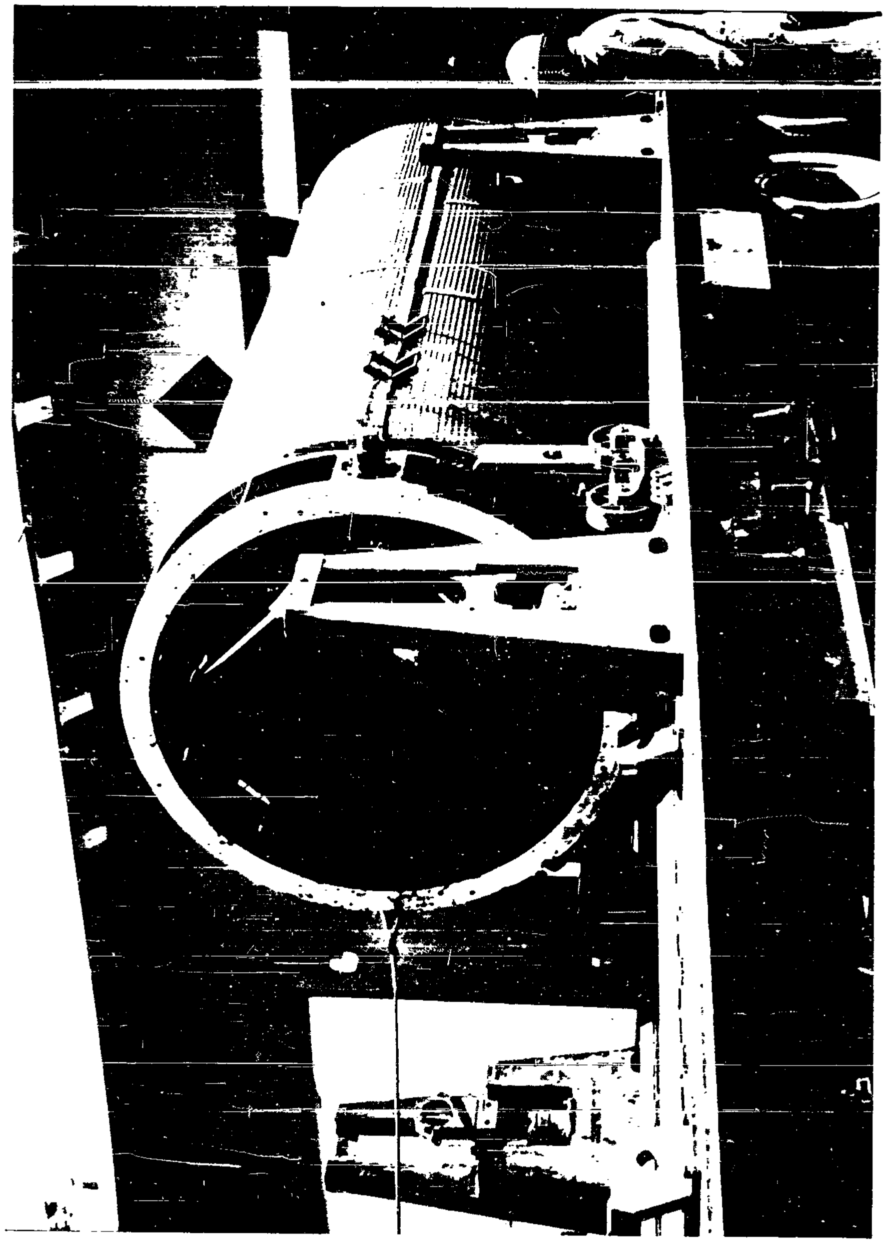
Slide 19 - for vertical testing, a crane with vertical lifting beam is attached to the aft trunnions of the harness. The crane then pivots the motor to the vertical position and moves it onto the stand. The motor is static tested in a nozzle up position.

Slide 20 - with the concept of silo firings, a new requirement of external insulation was imposed on the missile to protect the exterior from the intense heat before leaving the underground silo. By this time, the design of the motor was in its final stages and a new harness for production was feasible. The rings on the production harness were extended beyond each skirt to allow the external insulation to be applied without interference. This slide shows a motor with its production harness resting on rollers used to rotate the motor during external insulation application. The final design of the case was structurally strong enough to permit elimination of the heavy side beams.

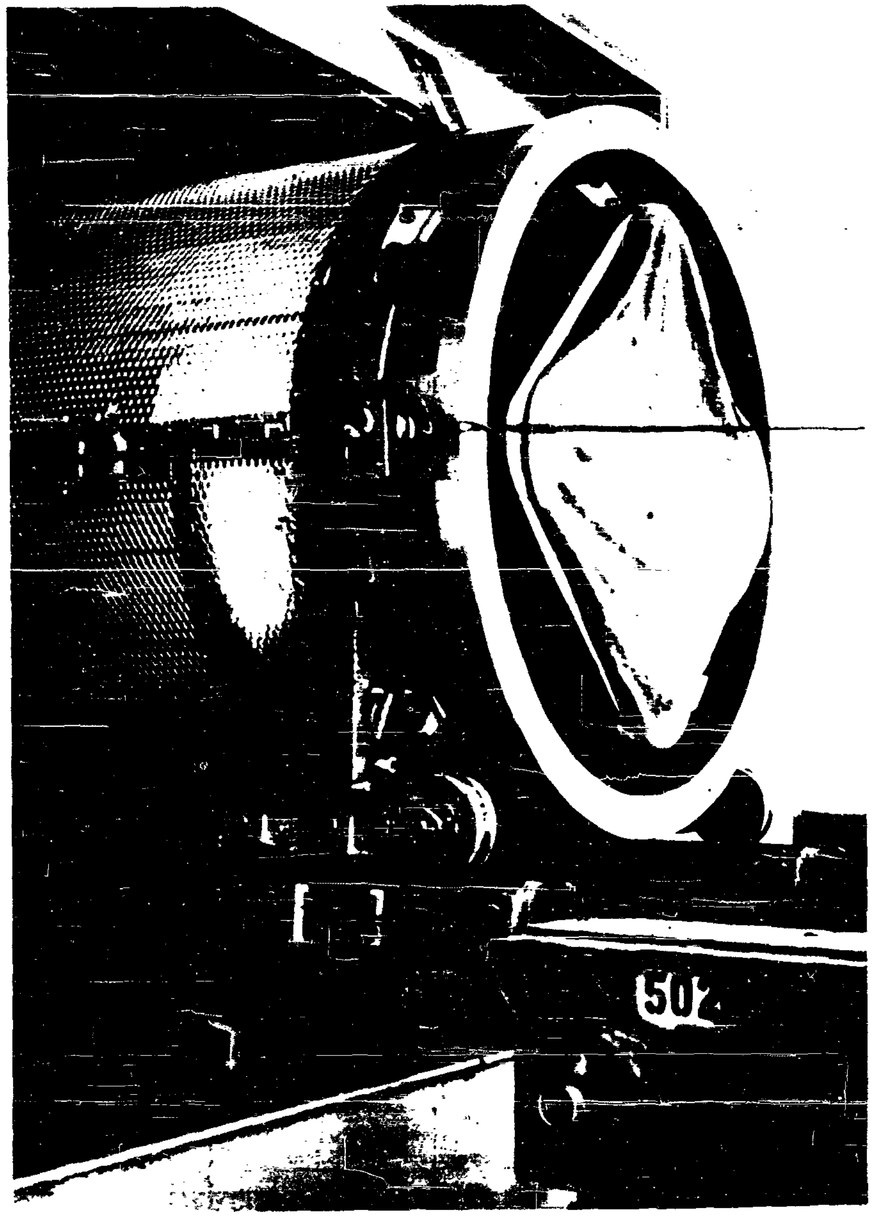
Slide 13



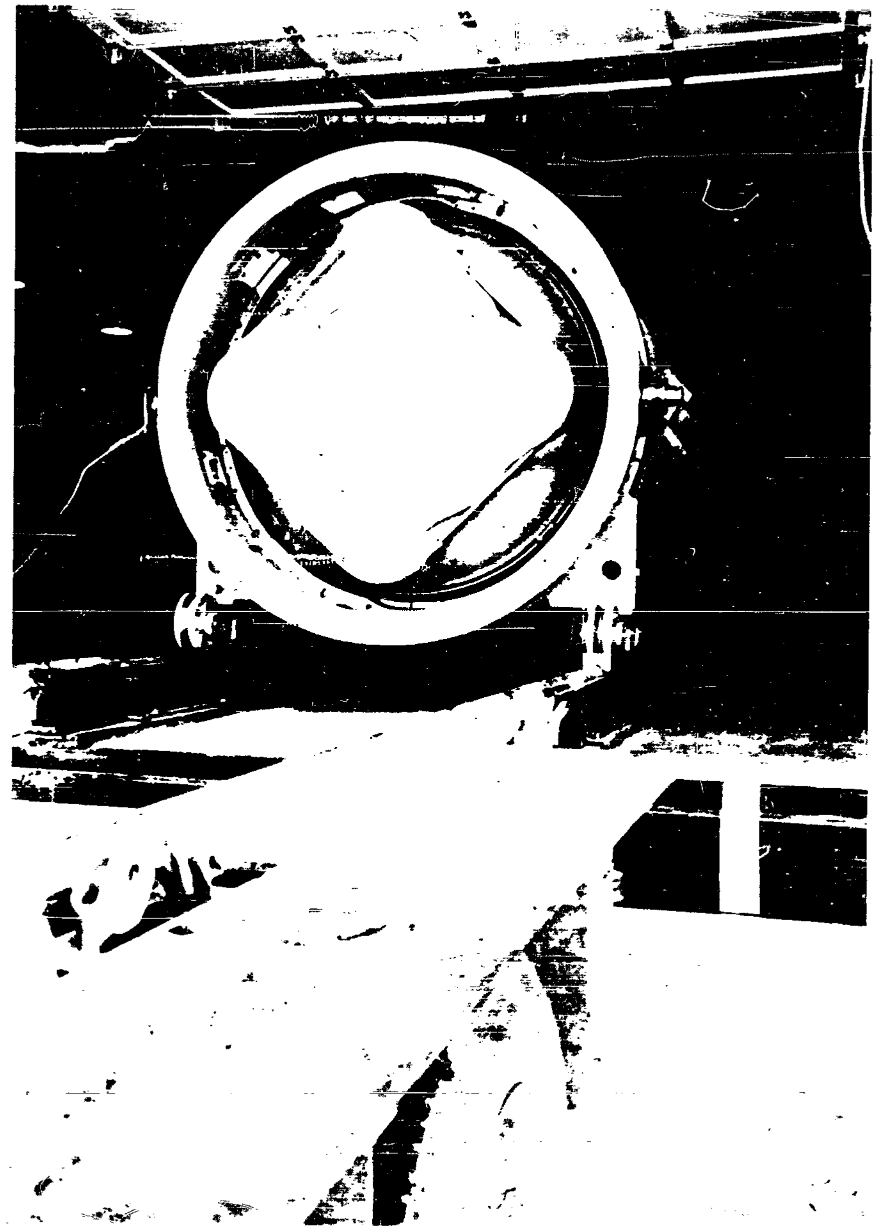
Slide 14



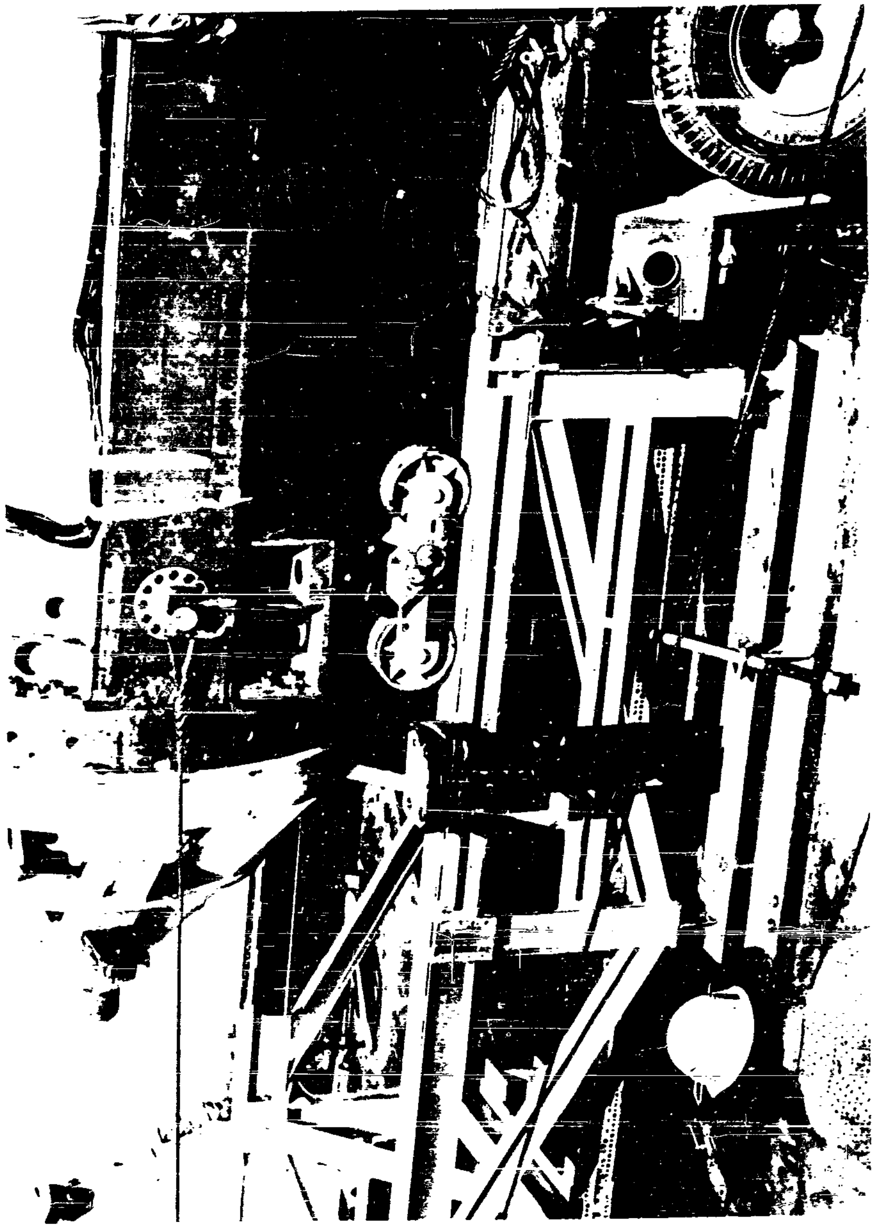
Slide 15



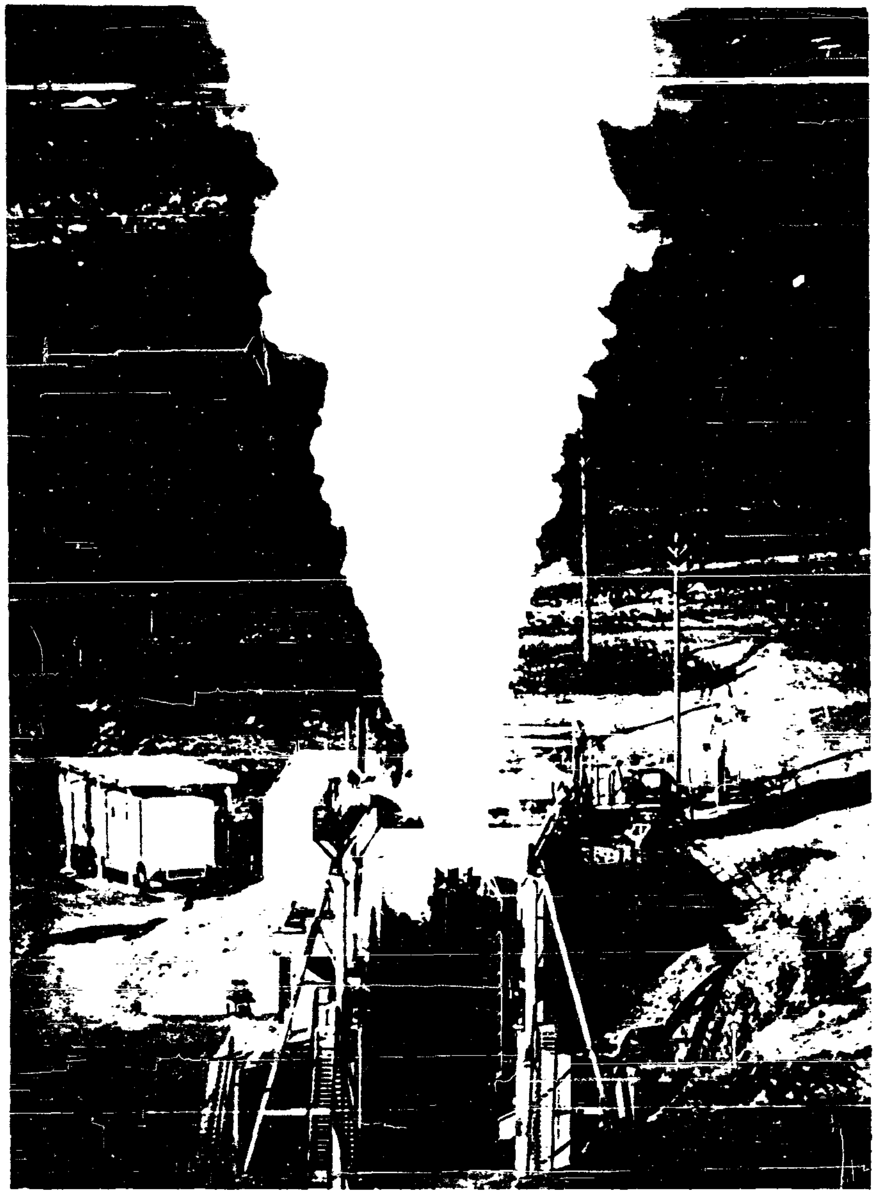
Slide 16



Slide 17



Slide 18



Slide 19

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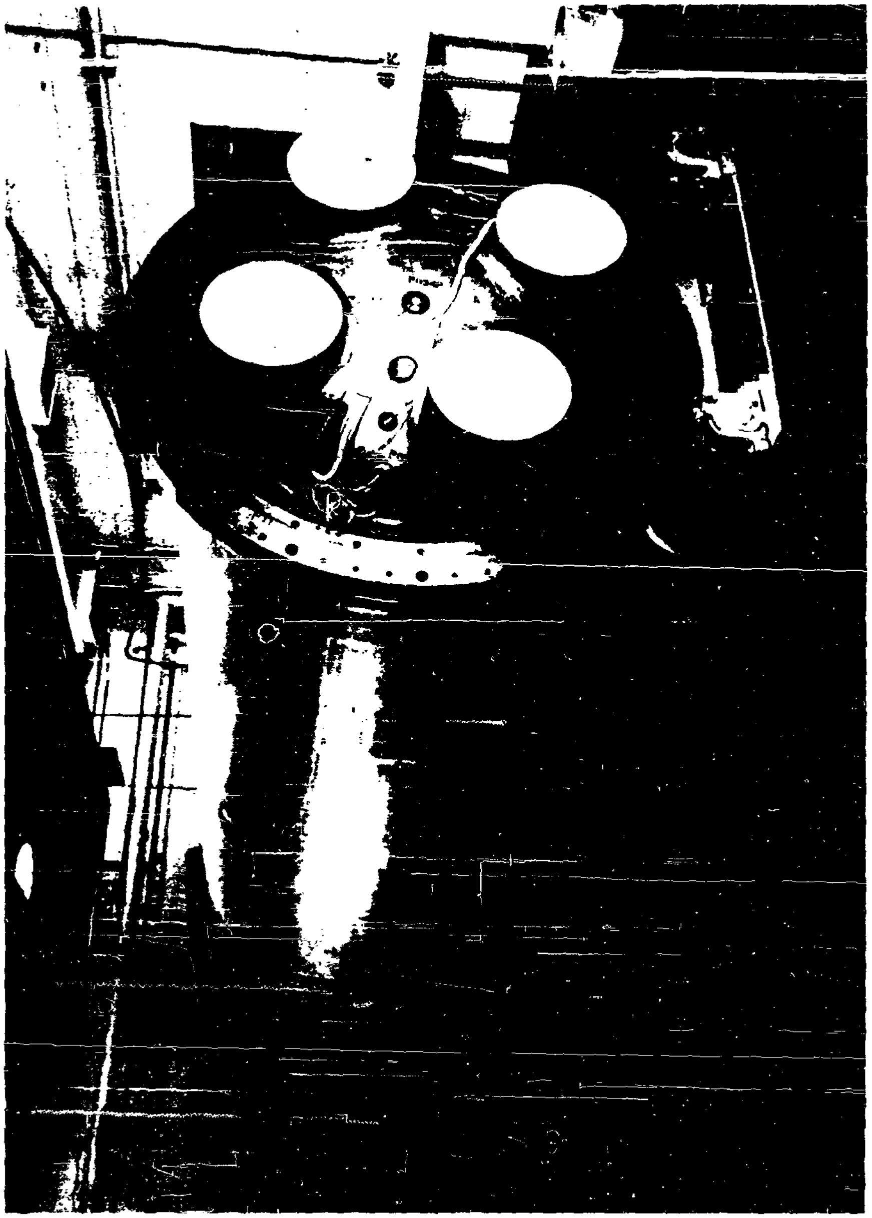

Slide 20

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The protective screens were carried over from the universal harness for case protection.

Our entire production plant was designed around the use of rails and the horizontal rolling method for movement. The empty case is brought into the plant and placed on a horizontal rotating dolly. While the motor is on the dolly, the production harness is installed. For case preparation, the v-groove wheels are replaced with rubber swivel wheels. The rotating dolly is lowered and the harness wheels engage the floor, allowing the motor to be rolled to any location in the building. After case preparation is complete, the rubber wheels are replaced with the v-grooved wheels and the motor rolled onto the handling carriage. It is then transported to the casting pit. Here the motor is rolled into a vacuum bell and the harness is secured to the bell. The bell is hydraulically tilted into a vertical position in a pit, the motor is vacuum cast, cured and the mandrel is removed: the motor is then removed for radiographic inspection and final assembly.

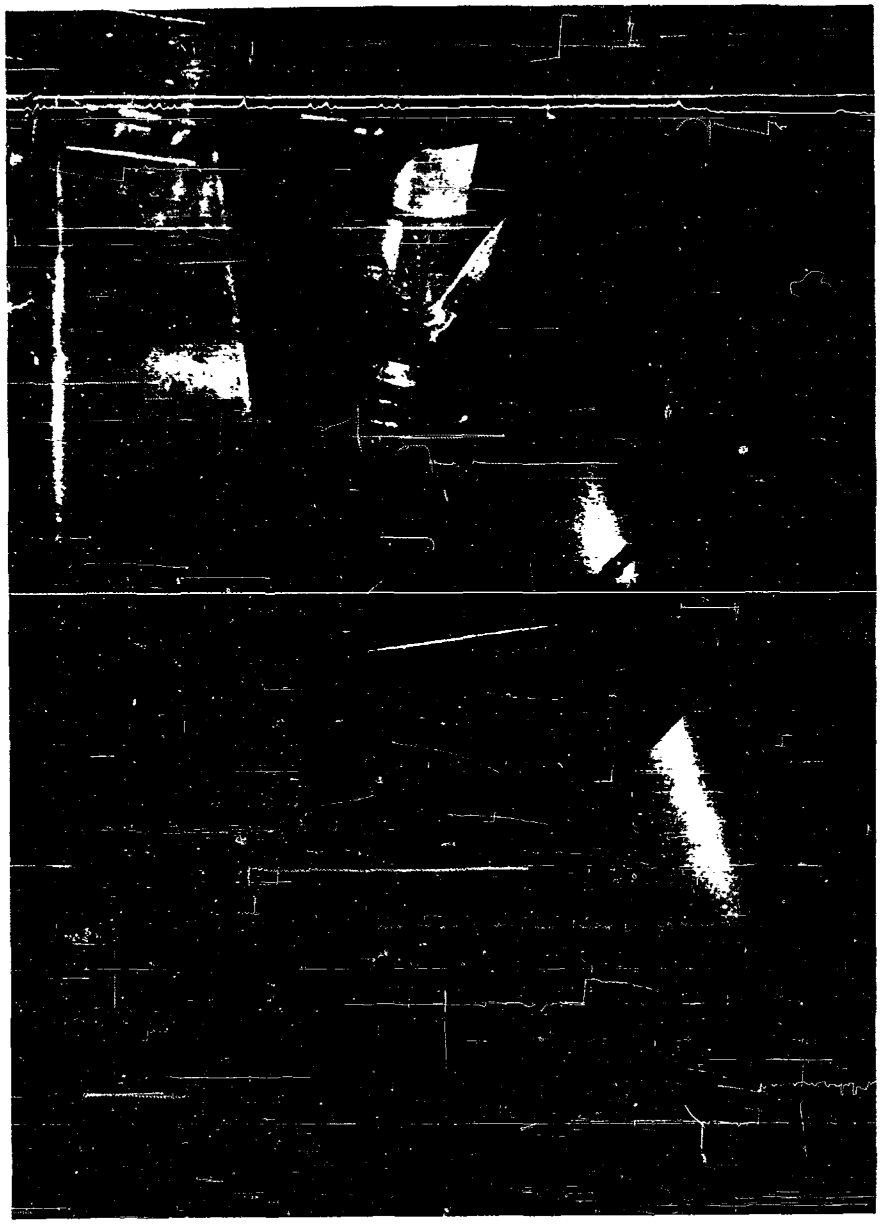
Slides 22, 23 and 24 - for delivery to the Air Force assembly plant, the motor is placed in a Boeing harness which is a cradle type harness that allows assembly of the missile. The motor is winched into the handling carriage with its conditioning cover installed for transporting. At the assembly plant, the motor is winched from the carriage into storage bunkers using the horizontal roll method. Here it remains until removed for missile assembly operations for flight.

The segments of segmented space boosters up to 160" in diameter can be handled using methods employed on the MINUTEMAN. The cost of an in-plant rail system for research and development operations is prohibitive because of the necessity of spacing facilities to comply with safety regulations. Most of the segment designs call for longitudinal dimensions about equal to the diameter, thus making the use of tilt tables awkward and unsafe because of the large moment created on the pivot. Gantry cranes with breakover stands and handling harness similar to the universal harness appears to be the most satisfactory method for handling. For in-plant transportation, the semi-trailer carriage with rails and trunnion supports is most economical.

In Slide 25, we are demonstrating the handling of a 120" motor segment. The harness consists of two (2) large metal rings joined with side beams. The inside diameter of the rings is larger than the outside diameter of the case. Between the rings and the case is a filler which is poured in place and allowed to harden. This provides infinite surface contact between the rings and case, keeping the case round and providing uniform support. Another advantage of this type harness is the cost. Because the inside diameter of the harness rings do not have tight tolerances, the fabrication cost is less. (Slide 26) This harness also allows some design change in the motor case, the difference in dimensions will be compensated by the filler material between the rings and case.

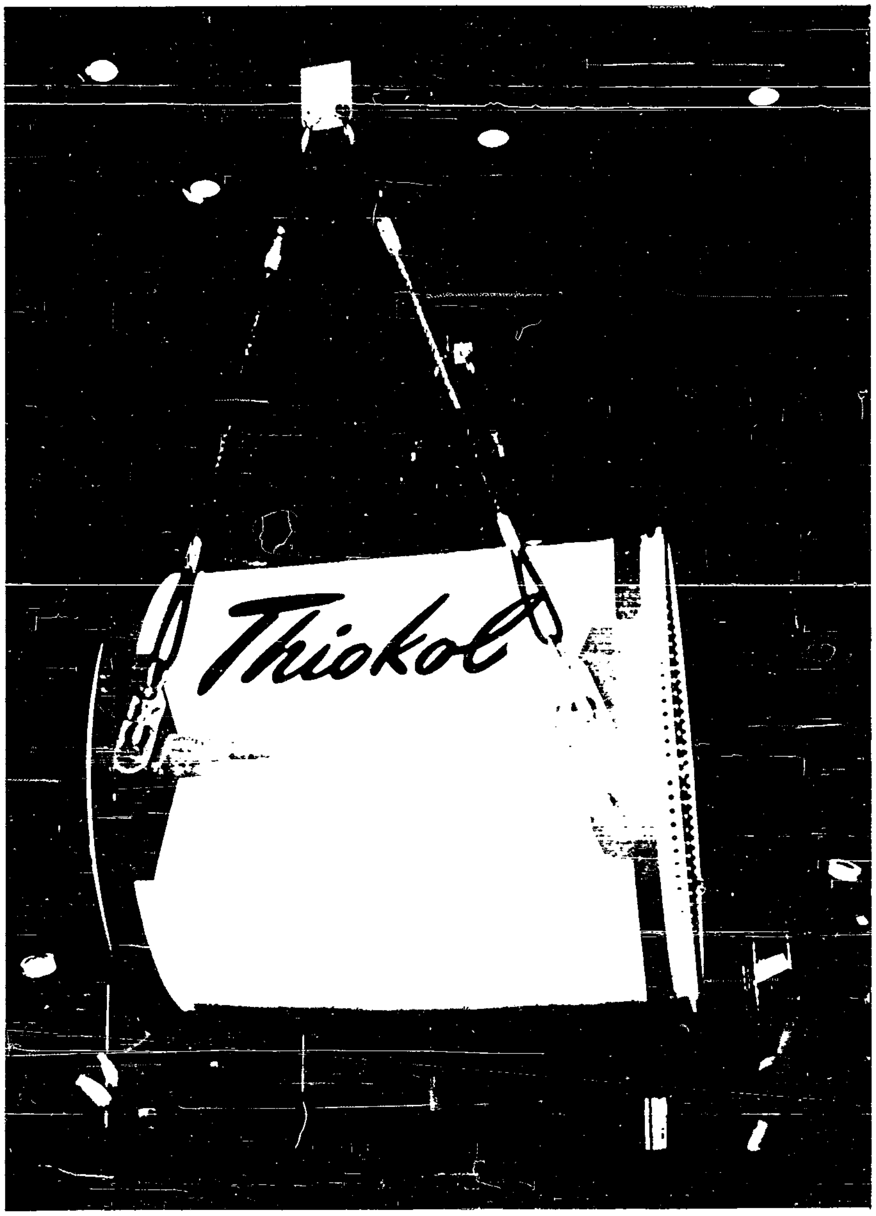
Slide 21

Slide 22



Slide 23

Slide 24



Slide 25

Slide 26

In Slide 27, we are demonstrating the handling of a mock-up of a 160" diameter motor segment. The harness, although not on this model, would be similar to that on the 120" segment.

Both of these segments can be processed using the pit concept. Commercial semi-trailers are available to be converted into handling carriages for highway transportation. Segments of this size can also be transported using a standard railroad flat car. There is no real problem in handling segments in this size range during processing. At the launch site, the most convenient way for clustering is to stack the segments as shown in this artists conception (Slide 28). From an engineering view, it is not quite as easy as pictured here, but with the proper guide and orientation equipment. this is the most economical method of clustering.

Motors larger than 160" segments cannot use highways or railroads for transportation. The only other feasible means is by water, possibly on barges. This limitation requires plant location with access of waterways to the launch site.

The monolithic processing of large space boosters, depending on its length and size, requires more specialized handling techniques. With this type motor, an interplant rail system becomes necessary for land movement. All movement should be by the horizontal roll method for maximum safety. Where processing requires the motor to be in a vertical position, tilt tables with counter balances could be used. On this large motor, the pit processing method reduces cost and increases the safety. Because of the weight involved, the pit would be modified to be half underground with embankments on three (3) sides forming the rest or upper portion of the pit. This would allow the motor to be tilted into the pit with the pivot at ground level. Throughout processing the center of gravity of the motor would remain at the same height plane as much as possible. After casting, curing, mandrel removal, inhibiting, final assembly of components, radiographic inspection, and finishing, the motor would be tilted back onto the rail system and rolled onto a barge. The barge would be towed to the launch area where the motor could be rolled onto a rail system leading to the launch pad.

Slide 29 - a handling concept that merits mentioning is based on canal processing. The motor would be placed in a harness of tanks similar to a life jacket. The harness would allow the motor to float just above the surface of the water. Based on a propellant specific gravity of 1.7 and using a motor with dimensions of 160" in diameter and 100 feet long, the harnessed motor package would be 110 feet long and 23 to 24 feet in diameter depending on the hardware used. By submerging the motor alone, its weight is decreased by approximately one half. Prior to casting propellant, the case would be placed in this harness and placed in a canal. Canals would connect the processing

Slide 27

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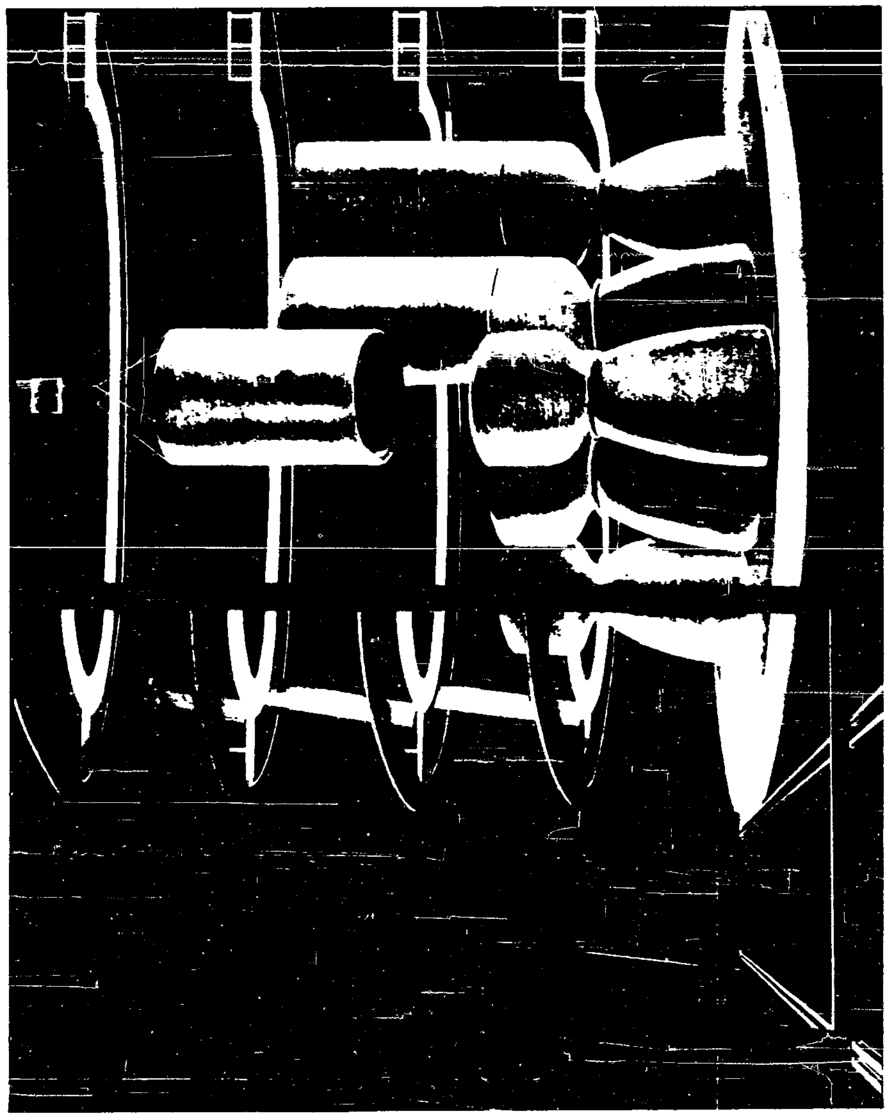

Slide 28

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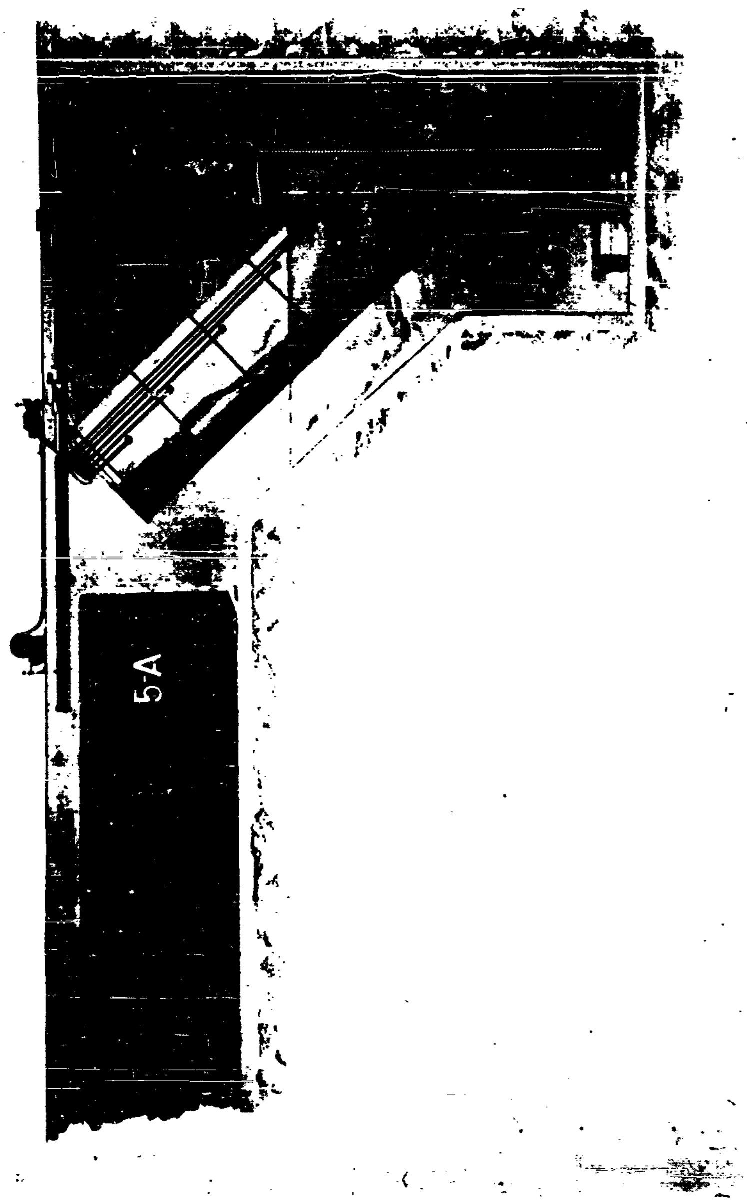
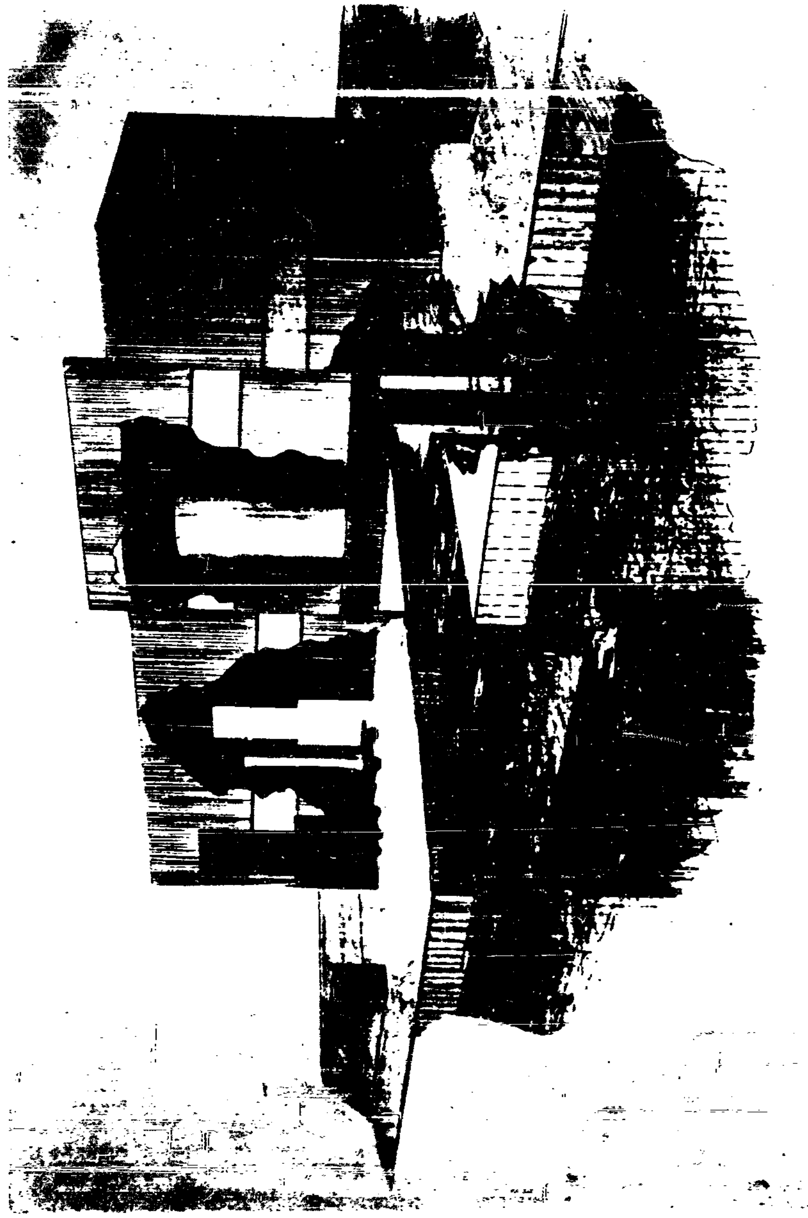


Slide 29

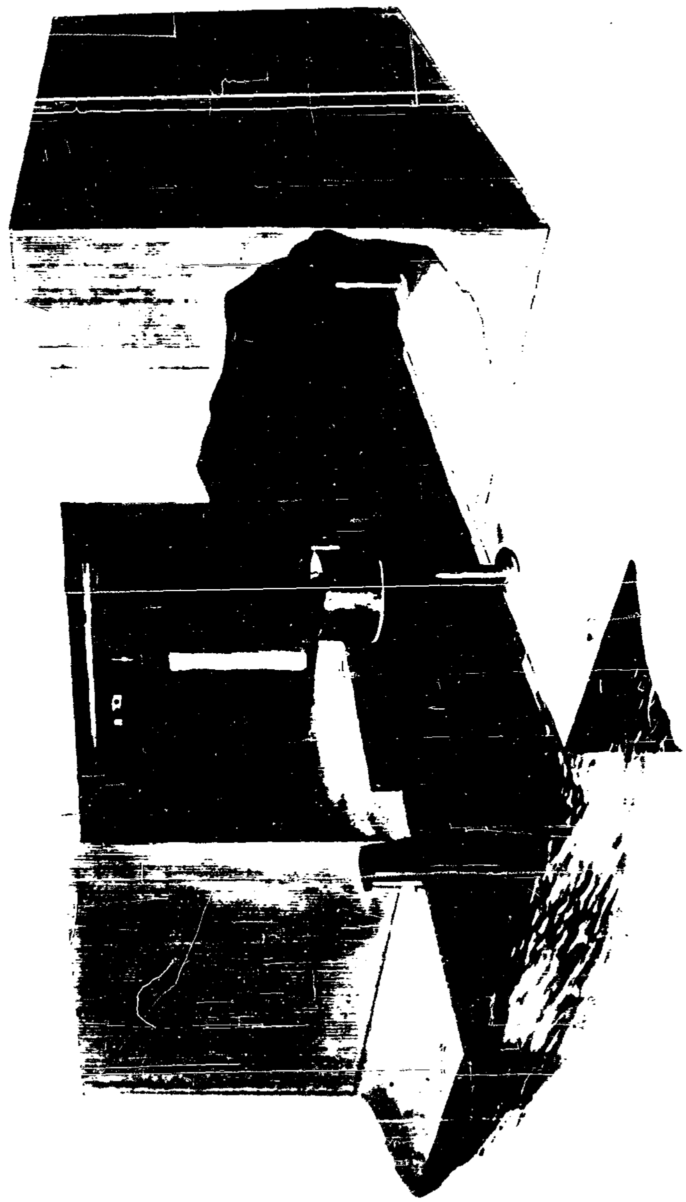
areas. To cast, the motor tugs on each side of the canal would tow the motor to a pit. Though not exact, this sketch gives us an idea of the following process. A canal lock would separate the canal water from that in the pit. The tanks on the head end would intake water causing a pivoting action. Control cables and winches would help pivot the motor. When in a vertical position, the motor would be lowered by intake of more water onto a stand. (Slide 29) The water would then be drained or pumped from the pit. (Slides 30 and 31) Portions of the harness would then be removed to provide working access to the motor. Casting through finishing operations would then take place in this pit. The harness portions would then be reinstalled and the pit flooded, the tie-down pneumatic locks released and the water pumped from the head end tanks. The water in the tanks could have been released prior to flooding the pits and weights attached to replace the water. This would probably be more easily accomplished than expelling the water from the tanks. The winches would again rotate the motor to a horizontal position. The canal lock would then be removed and the motor towed to a barge. The harness itself could also be used, in place of the barge, to transport it to the launching site. With this type of handling, the motor would less likely be damaged, dropped, or bumped, eliminating many of the safety hazards.

As the requirement for space boosters increase in size, or where clustering becomes unfavorable, or if a cheaper method of processing is required, launch site loading is both economical and feasible. This method eliminates handling of the loaded motor. One of the limiting factors of how big a booster motor can be built is the removal of the mandrel. There have been good results with a new study on segmented foam mandrels which allow the fabrication of an extremely large booster. Launch site loading would consist of positioning the empty motor on the launch pad. The empty motor could also be fabricated on this pad, if pad time were available. Insulating and lining could be accomplished on the pad or preferably prior to positioning on the launch pad. A ramp would be used to haul the propellant up and dump it into the motor. The propellant could also be moved up to the top of the motor by conveyor belts or buckets instead of hauling up a ramp. A large booster could either be plop cast similar to cement pouring or casted by a controlled rate method. We have experimented with a continuous propellant mixing plant which could be made to be mobile. With this set-up, the mixing plant would be moved next to the motor and a continuous flow of propellant would be cast into the motor. Automatic controls regulate the quality of propellant being cast automatically rejecting faulty propellant. This method will also work for clusters. This eliminates the safety hazard of lifting several million pound rocket motors and positioning or clustering them on the launching pad.

To reduce the safety hazards in handling, we have reduced the handling of the MINUTEMAN motors to a minimum by using the pit method of processing. The rolling transfer method on rails allows full processing without the use of cranes and removes the hazard of lifting. The canal processing for larger motors has the same advantages as the rail system while on site loading eliminates handling of a loaded motor.



Slide 30



Slide 31

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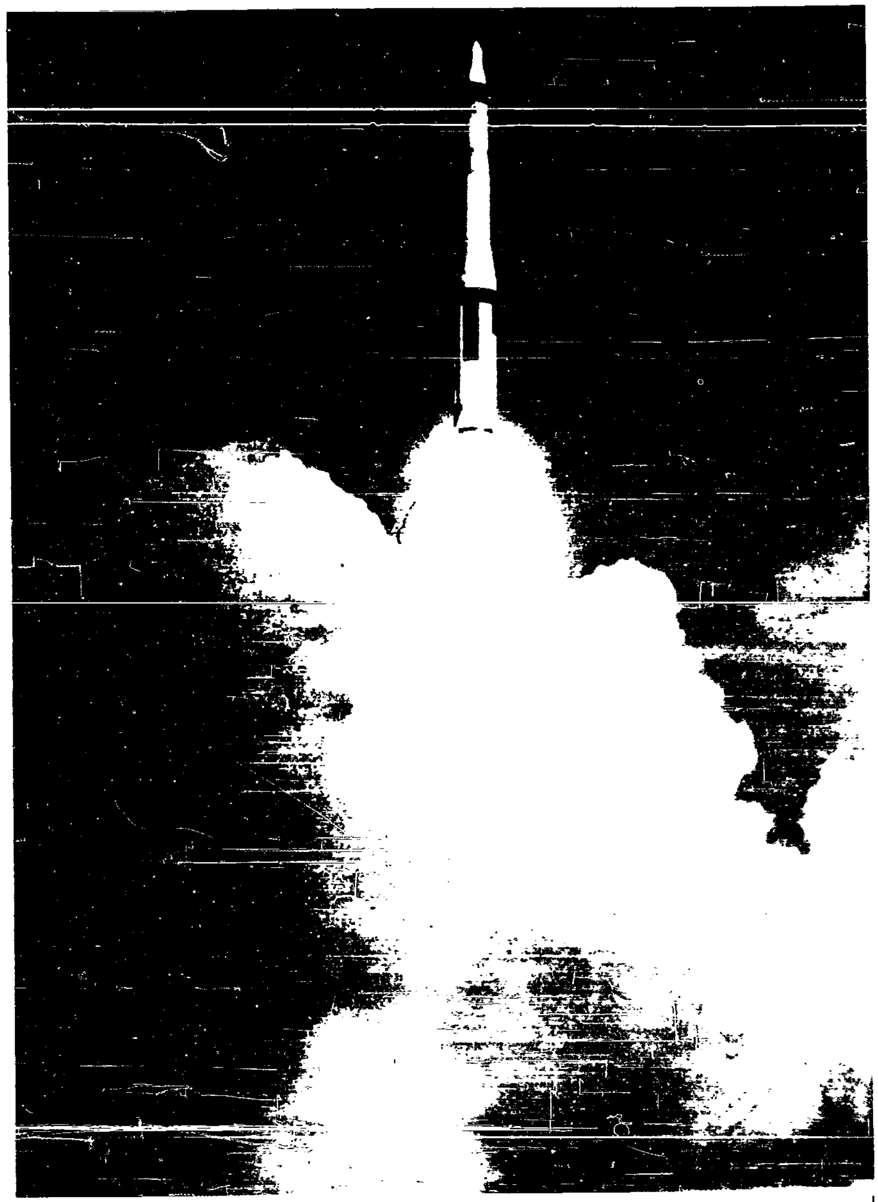

Slide 32

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ULTRA HIGH SPEED FIRE PROTECTION SYSTEM FOR SOLID PROPELLANTS

by
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At the 1960 seminar we presented a paper announcing the development of a new fire protection system having the capability of detecting a fire and discharging water in time intervals measured in milliseconds. The development of this system made it practical to consider the possibility of controlling or extinguishing fires in solid propellants. Much progress along this line has been made since your 1960 meeting, and this paper is a report to you on that progress.

For those of you who may not be familiar with the system, its speed of operation is attained by the use of two devices little used in the fire protection field before. The first is a solid state light sensitive cell which gives us detection with the speed of light, and the second is an explosive actuated water control valve which releases line pressure into the system in a few milliseconds. The sequence of events is briefly this: Light from the fire within certain wave lengths and above a certain intensity reaches the photo conductive cell or cells which send a signal to a transistorized amplifier in the control panel. The amplifier increases the signal sufficiently to detonate the primer in the water control valve. The explosive force of the primer releases a latch so that the water pressure in the line can open the valve and the line pressure is then impressed on the priming water that has been placed in all piping downstream of the control valve. This pressure is capable of rupturing or blowing off the closures at the discharge nozzles which, up to this point, retained the priming water in the piping. Water now issues from the nozzles onto the fire at full line pressure.

The addition of supervisory and test equipment completes the system.

Our test work started using a simulated cut-back machine furnished to us by the Long Horn Ordnance Plant, which is operated by Thiokol Chemical Company. The first slide shows this piece of equipment (Fig. 1). The next slide shows a closer view and a piece of plywood we used to represent the uncut surface of the grain. (Fig. 2).

Since it was felt that the most difficult fire to extinguish would be from a concealed ignition and, in this particular operation, the most likely place for ignition would be under a pile of shavings, propellant shavings were

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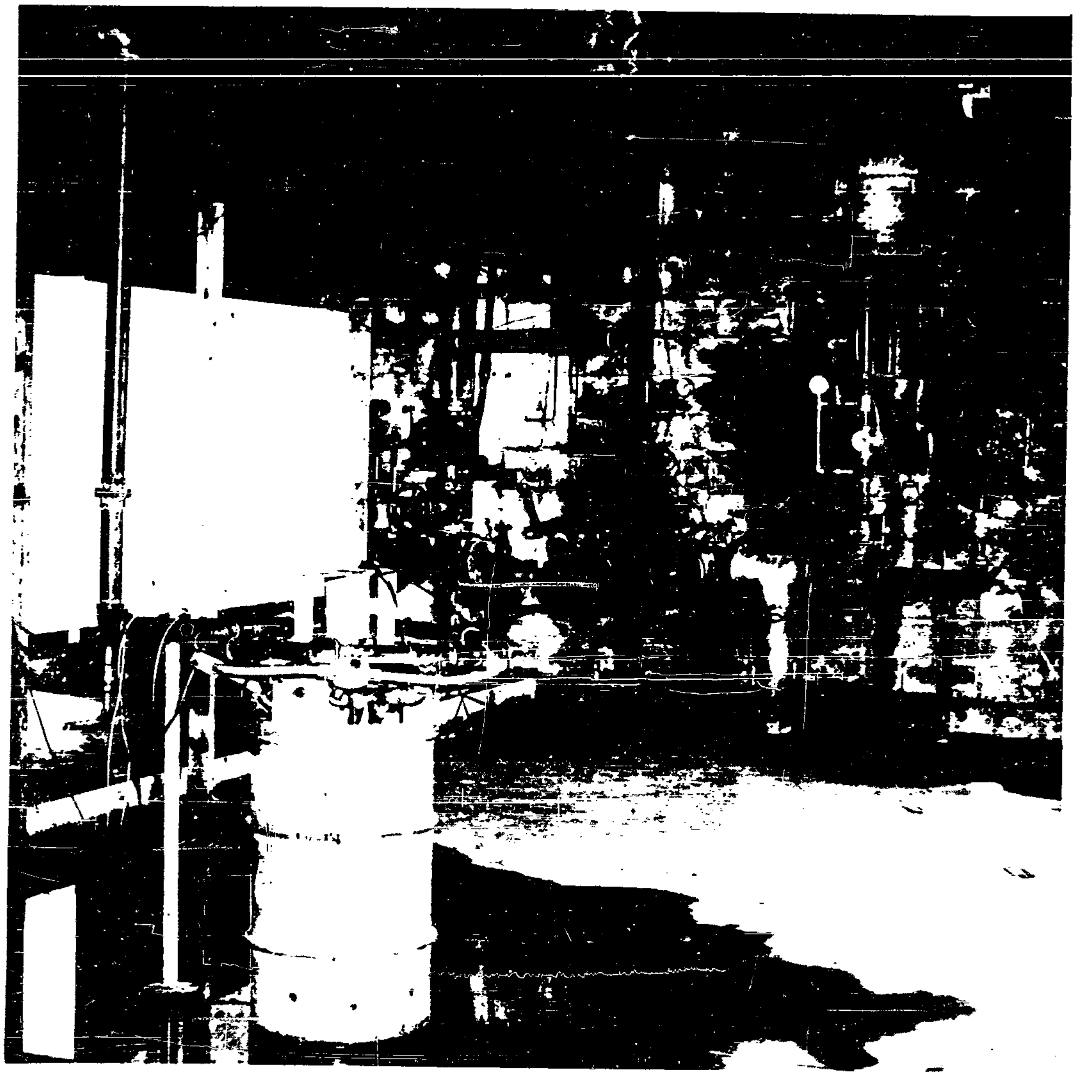

Figure 1

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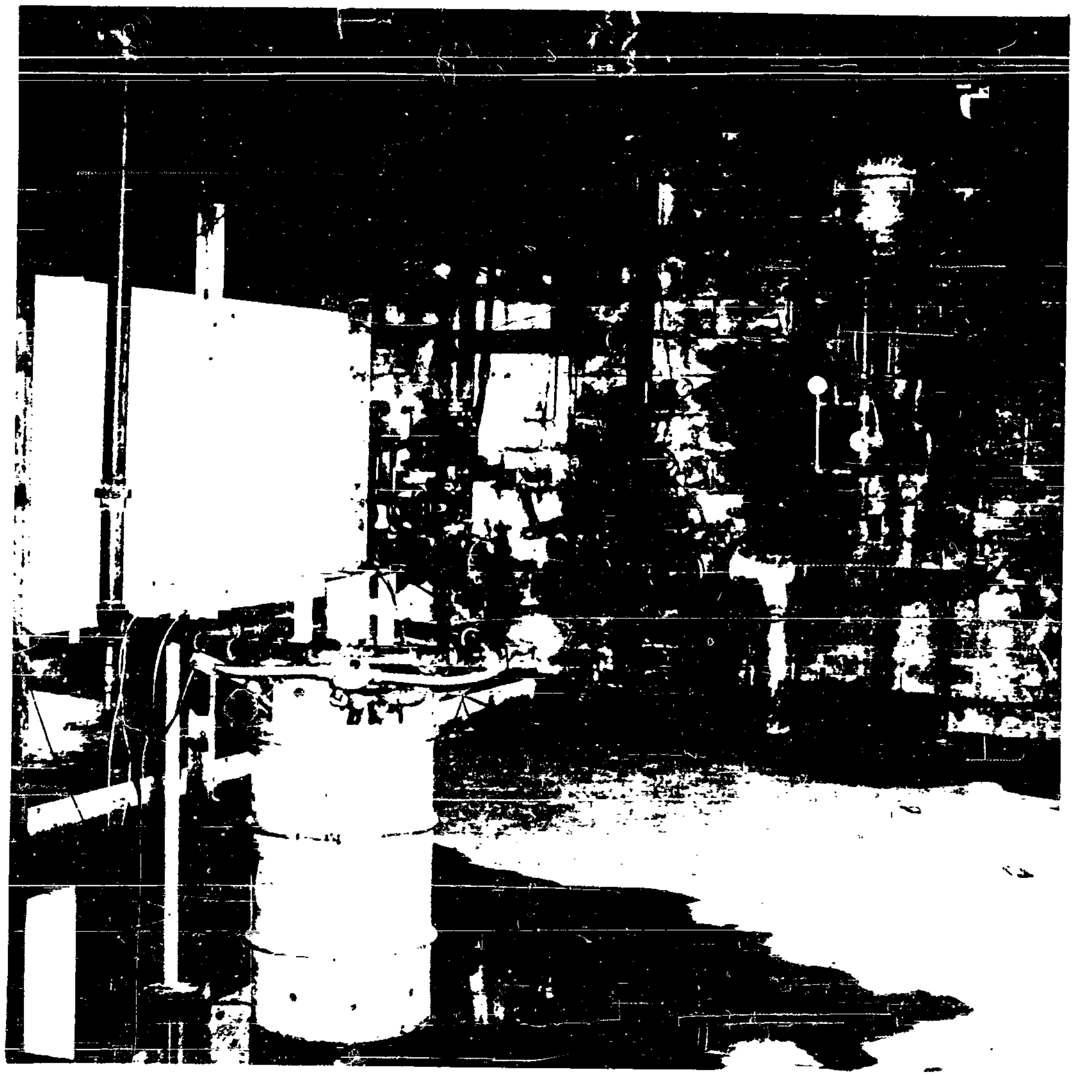

Figure 1

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Figure 2

placed on the plywood over a nichrome wire used as a source of ignition. The wire was heated, ignition occurred, the system operated, with the results shown in the next three slides of three different tests (Fig. 3-4-5).

After many such tests using different types of propellants, all of which resulted in extinguishment before the propellant was consumed, the next logical question was what would happen if the tests were run with the shavings on a live grain instead of plywood. Therefore, a chunk of propellant was set into the plywood and the igniter wire placed on top of it. Shavings were piled over the wire as before. After the test, the chunk of propellant appeared as shown in the next slide (Fig. 6). A slightly eroded area can be seen where the burning occurred. You will note that the burning did not reach the edges of the piece. Therefore, had the piece been larger it is logical to assume that the results would have been the same. This test showed that, for this operation and other similar ones, the fire could be stopped before the grain became seriously involved, thus saving the equipment, reducing the hazard to personnel, if they are in the area, and possibly having a salvageable grain, depending on the type of propellant involved, and how far the cutting operation has progressed.

By this time it became apparent that the system was so fast that small samples of propellant could be used, and a cubic centimeter has become more or less the standard sample. A nichrome wire is again fed through the sample as an igniter. The next slide is typical of the results of these tests (Fig. 7A - 7B). We do not claim to be able to do this with every known propellant. However, of those we have tested to date, and there have been many, there were only two we could not detect and extinguish in the one cubic centimeter sample size and these were successfully handled using a larger sample.

The key to the success of this system is its speed of operation and we are often asked just how fast it is. This is a difficult question because there is no one answer. For example, one of our installations operates in about 40 milliseconds whereas another of our installations operates in about 240 milliseconds.

System operating time is, at present, a subject to which almost as much time and words could be devoted saying what we don't know as what we do know. A logical first question on the problem of propellant fire protection would be: How fast does water have to be applied in order to have a good chance for extinguishment? The logical second question is: How can we get water to the fire this fast?

Figure 3

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Figure 4

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Figure 5

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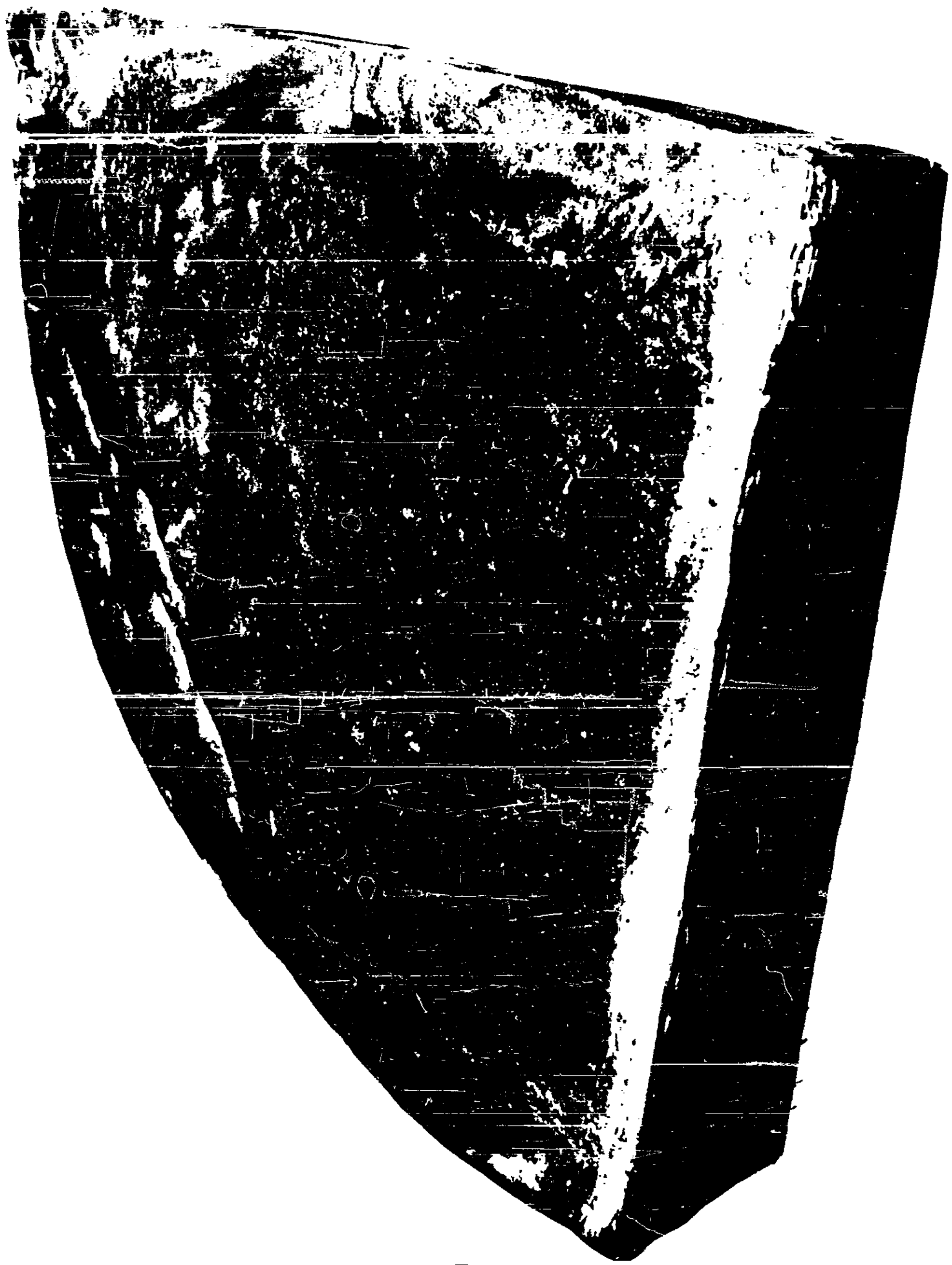

Figure 6

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Figure 7A Before Test

Figure 7B After Test

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The first question, by its nature, is directed to the propellant manufacturer; the second question to the fire protection engineer.

The propellant manufacturer will, of course, qualify his answer by citing the variables of type and geometry of propellant, the location and type of ignition mechanism, the initial temperature of the grain and the degree of confinement and consequent possible pressure build-up.

The gist of this is that it is virtually impossible to get a specific answer to the question of how fast water has to be applied in order to be effective.

This leaves the fire protection engineer without a finite target in his effort to produce rapid detection and water delivery. Without a specific target, we do the only logical thing and design our detection and water delivery to be as fast as possible within the limits of reliability and economic and physical feasibility and, in addition, we test as frequently as the availability of propellants and facilities allows in order to develop a library of information.

Let's now consider some of the factors that affect the fire protection system operation time. We divide this time into two phases; one is the equipment operating time, that is the time from detection of the fire to the time this signal has been amplified and fired the primer in the water control valve.

The second phase is the time required from primer firing to the time water makes its exit from the fire protection nozzles. The equipment operating time, as here defined, is the fastest phase and has a fairly constant value in our system in the order of 2 or 3 milliseconds.

The second phase of water delivery time is, of course, the source of most of the time consumption and is dependent on several factors. One of these factors is the completeness of water prime of the piping system from the explosive valve to the nozzle closures. Our tests show this to be a vitally important factor since, in general, an air pocket constituting about 5% of the total volume of the system will cause about a 100% increase in operating time.

Water supply pressure is another important factor in determining water delivery time. Both analysis and tests show that all other factors being equal, the water delivery time is proportional to the square root of the water supply pressure. This would mean, for example, that if the supply pressure on a specific system were increased from 50 PSI to 100 PSI, the water delivery time would be reduced by about 30%.

Since our test times are concerned with the period from water at rest to water exit from nozzles, frictional effects and coefficients obtaining during steady flow may or may not apply during

unsteady flow. This problem is still being studied, but fortunately most ultra high speed system designs are such that water delivery time, as defined, is practically independent of pipe line friction losses and almost solely due to inertia effects. We are, therefore, able to predict reasonably accurately what the fire protection system operating time will be provided we know the pertinent facts as to pressure, nozzle characteristics and pipe sizing and configuration.

In order to design the fastest feasible arrangement, we request of the propellant manufacturer the following:

Proper ambient conditions for the photoconductive detectors.

Good water supply pressure.

Short and straight routes for the fire protection piping from water supply to nozzles.

We now have some slides on actual installations (Fig. 8). Many of you will recognize this as a Baker Perkins 150 gallon mixer. There are actually two systems on this machine. A conventional rate-of-rise system protects the exterior, and the ultra-high speed system protects the interior of the bowl. The systems are interlocked so that when one operates, the other operates also. A closer view shows the interior system (Fig. 9).

The next slide shows a lathe operation (Fig. 10).

From these examples, it can be seen that each installation is specially designed and tailor-made for the individual hazard being protected.

Our usual procedure is to first determine by test that we can detect a fire in the propellant involved fast enough to be able to control or extinguish the fire. Then we make a survey of the equipment and, working with the Owner's engineers, select locations for the detectors, nozzles, control panel, water control valve, and piping so as not to interfere with the operation and still accomplish our purpose. Where there are special problems, we sometimes make a mock-up, as illustrated by this slide of the mixer mock-up (Fig. 11). Here we had to select nozzles having the proper volume and angle of discharge to completely cover the top plate above the bowl.

In this example of a horizontal boring operation (Fig. 12) we had to develop special nozzle tips to concentrate the water in the narrow annular ring around the tool and in the fingers of the star.

Many representatives of propellant manufacturers have come to our test field in Cranston, Rhode Island, to witness tests of this equipment and discuss their special problems. I would like to extend an invitation to any of you who would like more information or to discuss specific applications to visit us also. If you prefer, we will, of course, visit you at your plant.

If you have any questions now regarding these systems, I will be glad to attempt to answer them.

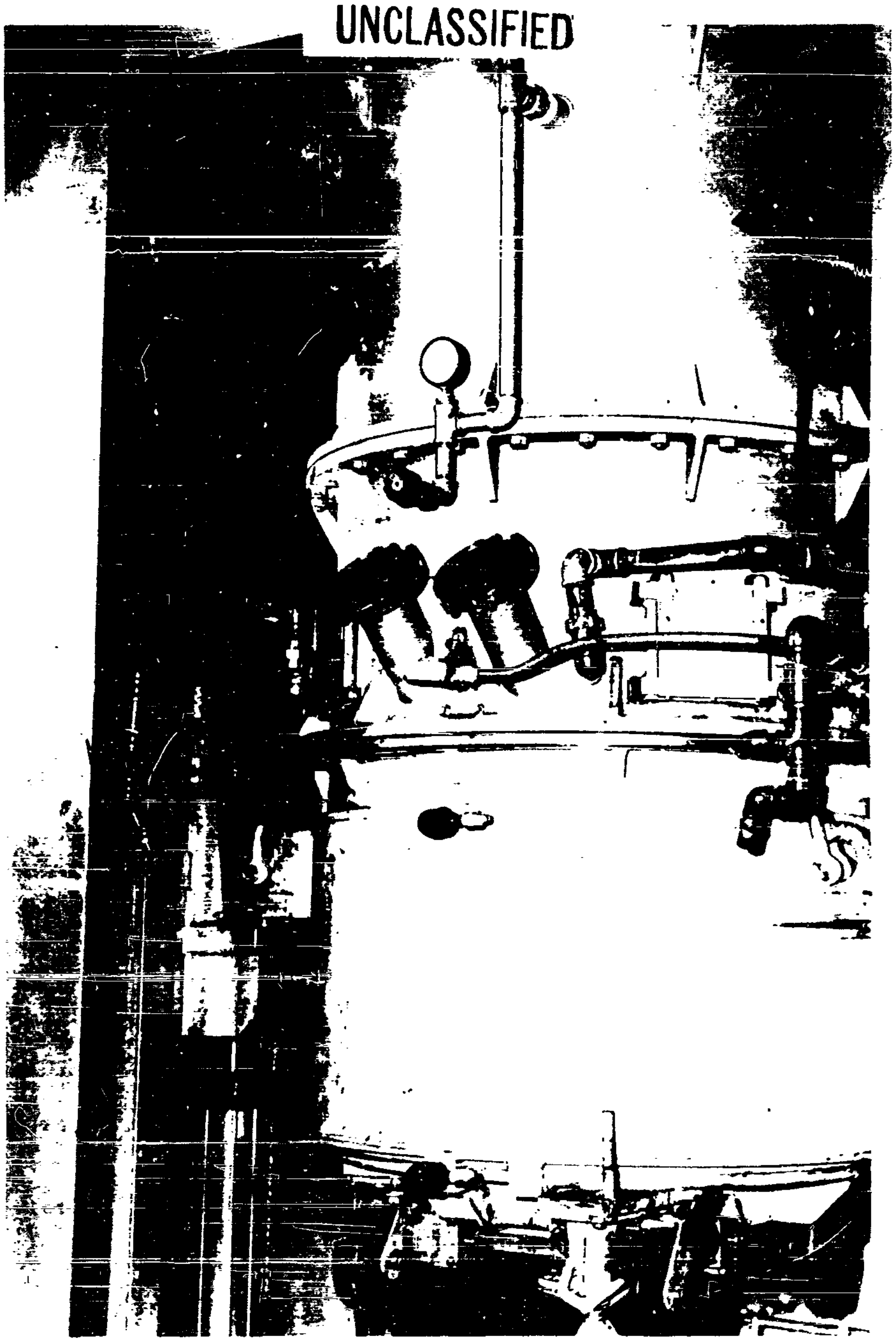

Figure 8
Ed. Note: Since the Seminar, a fire occurred in this mixer. The system operated, with the result that there was no fire damage to the mixer and it will be back in operation in a relatively short time after repair of minor mechanical damage. Information provided by author of this paper.

Figure 9

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Figure 10

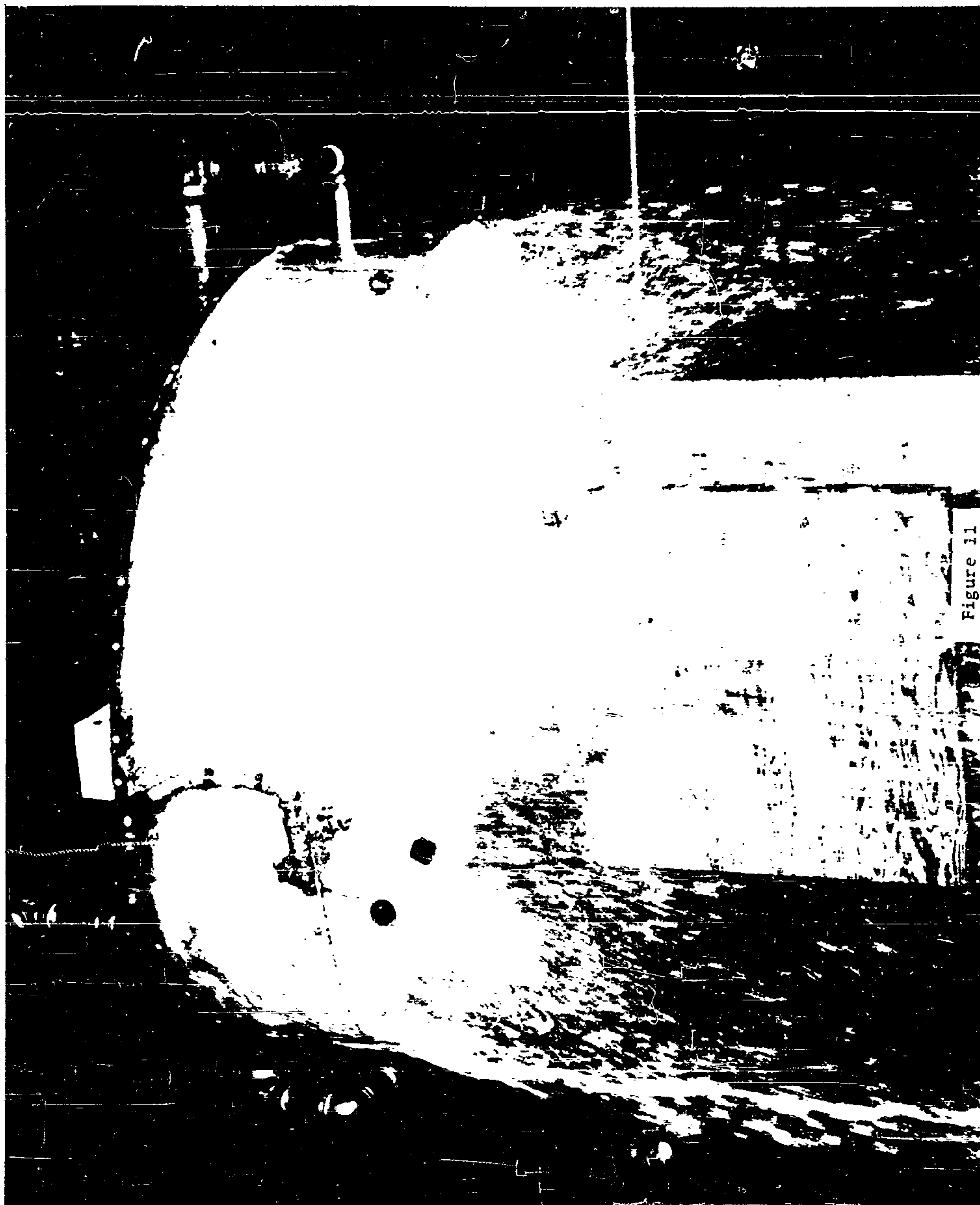


Figure 11

Figure 12

Mr. Cretcher: Can you tell us what type photo conductor you're utilizing?

Mr. Averill: It's a Clearex cell which has a response range basically in the infra-red but it does get over into the visible light. We use various filters to select sections of the spectrum that we wish to work with depending on the type of light produced by the propellant involved but there is a certain amount of versatility to this effect.

Mr. Bell: I have a couple of questions. I was interested in this same question on the detector, what the possibilities of false detection due to visible light might be. Another was, what about most of these safety devices? It's rather important to have a capability for testing them out,- what revision do you make for this?

Mr. Averill: Those features have all been taken into consideration in design of the system with reference to false operation due to ambient light, the fact that we're operating in the infra-red range does give a certain amount of protection there, however, the directionality of the cell - we inclose the cell in a sleeve so that it is a directional detector rather than detecting 360° so that it will only receive light from the area that it is directed at. The sensitivity of the system can be adjusted by a gain control in the amplifier so that we can over-ride ambient light conditions with a sufficient factor of safety so that somebody comes in with a white shirt on or something like that, the illumination changes, it isn't going to effect the system. We take light meter readings on the brightest sunny days and we figure the angle that the sun comes in the windows at the different times of day and make sure the cells are not so directed that the sun will shine in on them and all these things are looked into. As far as testing the system is concerned, there is equipment so that it can be completely tested out. There is a small grain of wheat-type light built into the detector exterior to the viewing window, that is, this is the most exterior thing on the detector and by depressing a push-button on the control panel, this light is lit and shines thru the window and you get a response signal on the control panel which indicates that the window is clean, the cell is able to see, the wiring between the detectors in the control panel is intact and the system is in operating condition. We also have another test circuit whereby depressing the button you put a trickle current thru the primer charge in the water control valve which again gives a response on the panel which shows that you have integrity of the primer circuit.

Mr. Saffian: This may be a take-off on a previous question. In your specific test, did you ascertain that the lights from the nichrome wire would not set off the cell?

Mr. Averill: Yes, we certainly did. The intensity of glowing nichrome wire is far below that required to give actuation. We couldn't over-ride normal ambient conditions if the cell were allowed to be - the

basic cell itself certainly is sensitive enough to detect a nichrome wire. However, the way we have it shielded in the system and with the gain control of the amplifier cut down, we are able to override that amount of light very easily so we definitely know that we're not getting operation from the nichrome wire itself. It takes the light of the burning propellant to actuate the system.

Mr. Peak: Do you care to comment on the cost of these systems?

Mr. Averill: This of course varies with the equipment being protected, just how extensive the hazardous area is, how far you have to go for the water supply, etc. Every installation is tailormade for the particular hazard and, of course, the amount of equipment, difficulty of installation, etc., varies. However, the average price of the dozen or more installations we have made runs in the order of $3,000 or $4,000. The Baker-Perkins mixer of which we have two such installations now, runs a little closer to $10,000 because it is a dual system. We have both the conventional rate-of-rise and the Primat which is the trade name we used for this ultra high speed system on the same machine so that runs the cost up. For a basic Primat system on an average size piece of equipment, I would say $3000 to $4000 as an average price range.

Mr. Settles: We have participated with Grinnell in some of their development work and I just want to make one comment Mr. Averill. You mention two components in this time lag between detection and doing any good on the fires. There are actually three I think. One is the functioning of the mechanical equipment, the other is to apply pressure to get water started out of the nozzle and the third is the travel of the water from the nozzle to the fire. This is probably the longest time lag in the entire system and our fire protection people have come up with a rule of thumb that if you've got 100 PSI on your system, it takes about 30 milliseconds for the water to travel every foot between the head and the fire. So if you locate your head quite a distance away from a fire, you are trying to defeat the purpose of these folks who are trying to help.

Mr. Averill: That's entirely correct Jim. Thank you very much. We do attempt to get the nozzles as close to the hazard as possible to cut down this air travel time.

Mr. Queen: I note that you did have some illustrations there on the vertical mixer, I'm also sure that you've been questioned a number of times on the horizontal mixer. Have you anything to report in the way of progress in this, in the way of detection and also delivery, etc.?

Mr. Averill: You are correct, we have been questioned on the horizontal mixer, however, we have been given no specific problem "what would you do with this particular mixer? All our discussions have been on a general

and theoretical nature and about all I can say is the same principles of system operation apply, rather it's a core popping operation, a cut-back, a machining, a mixing, or what have you, it pretty much boils down to job engineering as to just how you would adapt the equipment to a particular operation.

RECENT DEVELOPMENTS IN THE CONTROL OF SHIPBOARD MISSILE STOWAGE HAZARDS (U)

by
Mr. S. McElroy
U. S. Naval Weapons Laboratory, Dahlgren, Va.

Today's Navy is the recipient of a large percentage of the peacetime production of missiles. The Navy employs missiles designed for various applications including underwater-to-surface, surface-to-air, air-to-air, air-to-surface, surface-to-underwater and underwater-to-underwater. Practically all of the Navy's missiles are at some time in their logistic history, carried and handled aboard, or launched from a Naval vessel.

The employment of a variety of missiles aboard ship, and in large quantities, imposes problems that may not be common to other branches of the armed forces. Ship's personnel must literally "eat and sleep with their missiles", since missiles are stowed and checked-out in spaces adjacent to personnel living spaces, and are often moved through corridors and spaces used for living purposes. When missiles are being carried in supply ships, or in stowage aboard operating ships, it is necessary, of course, to conserve precious space by placing the maximum number practicable in a given stowage area.

The conditions mentioned dictate that special consideration be given by the Navy to the practices, procedures and equipment necessary to assure the safe employment of missiles, one aspect of which, is stowage. Needless to say, a general calamity in a stowage space involving detonation of explosive and conflagration of propellant components could well lead to the loss of a ship and its personnel.

Slide No. 1 shows a typical flow chart for the transfer of the SPARROW missile aboard aircraft carriers of the CVA 59 and 60 classes. Slide No. 2 shows an arrangement of SIDEWINDER missiles in a typical magazine to obtain the maximum stowage density. Slide Nos. 3, 4, and 5 show typical "ready service" magazines for the TARTAR, TERRIER and TALOS missiles respectively.

In considering the conflagration of propellant components within a missile magazine, two separate conflagration phases are conceivable; the ignition of one or more propellant components initially, and the subsequent ignition (or chain ignition) of other propellant components not involved initially but which result from the primary ignition. It is also conceivable that if only a limited number of components are involved initially, precautions may be possible which may prevent, the subsequent chain ignitions. Of course, if a large number of propellant components are involved in the primary ignition, or if high explosive components such as warheads, are involved, the prevention of subsequent propellant ignitions may be impossible or impracticable.

Initial ignitions per se will not be discussed in this presentation other than to point out that their probability during peacetime is undoubtedly increased by the extent of day-to-day activity in and around magazine areas and weapon check-out spaces and by such ever-present possibilities as the collision of ships and shipboard fires. It should be noted that numerous efforts are being made, or have been made to reduce the likelihood of primary ignitions. These include efforts to dispell potential hazards from electromagnetic and other radiations, grounding procedures, handling and checkout safety procedures, selective location and structural integrity considerations during design of the magazine, and so forth.

As mentioned, chain ignitions are those that occur subsequent to primary ignitions and are caused directly by the burning of these initially affected units. It is considered that there are two "processes" or combinations thereof by which chain ignitions may occur. These are represented schematically in slide No. 6 and include cook-off as a result of an increase in the general magazine temperature and impingement of high velocity, high temperature gases on the propellant grain of an adjacent unit, either directly from motor-to-motor or upon reflection from a bulkhead or other structure.

It should be noted that if a primary ignition occurs, burning of the affected units may be either propulsive or nonpropulsive, depending upon the make-up of the motor and upon whether or not the affected motor ruptures. This is also depicted in slide No. 6. In a motor assembled to be nonpropulsive, the exhaust of gases occurs not only through the nozzle of the motor but also through another opening designed to counter the nozzle thrust. In the case of a ruptured motor, most of the exhaust gases may be expelled through the fissure in the motor case. In a propulsive burning, all gases are expelled through the nozzle only. Propulsive burnings because of their vigor are more apt to produce chain ignitions by gas impingement.

Extensive efforts have been conducted at the Naval Weapons Laboratory, Dahlgren, Virginia during the past six years to prevent, where possible, the occurrence of chain ignition of missile motors and engines. These efforts have been carried out for the Bureau of Naval Weapons and the Bureau of Ships. Numerous systems have been developed to prevent the chain ignitions, whether the "donor" motors are expected to burn propulsively or nonpropulsively. These systems include magazine sprinkling, water injection, magazine venting, plenum chambers and ducts, shielding, and protective closures and containers. In addition to these, consideration is normally given to arrangement within a magazine and to the segregation of unlike propellants. Most of these systems are represented schematically in slide No. 7.

Two types of automatic sprinkler systems are now being employed in the shipboard spaces used for stowage or handling of missiles and components. One system was developed for the Bureau of Ships and is in common usage in the ship's magazines of missile launching and AE-Supply-ships. The other system was developed for the Bureau of Weapons initially for gun mounts; however, it is now in use in missile system magazines such as the TARTAR GMLS Mk 11 and Mk 13 magazines.

The BUSHIPS system is dual sensitive, employing a rapid temperature rise detector called a heat actuated device (HAD), and a slow temperature rise (fixed temperature) detector called a fixed temperature unit (FTU), each connected independently to opposite sides of the pressure sensing diaphragm of a pneumatically released pilot (PRP) valve.

The BUWEPS system is also dual sensing; however, it combines the rapid temperature rise detector and the fixed temperature detector in one unit, with a common connection to one side only of the pressure sensing diaphragm of a PRP valve. With this arrangement, the inlet to the other side of the diaphragm is blanked off. This system is shown schematically in Slide #8.

In addition to the sensing portion of each system, control portions are also provided to initiate water flow through the system piping.

Both systems employ a hydraulic circuit or linkage between the PRP valve and a main control valve, with salt water as the hydraulic medium.

Both systems were designed for ammunition magazines, gun mounts and similar areas. The systems were designed primarily to control fires within these areas or to reduce the temperature resulting from fires in adjacent areas, in order to prevent cook-off of explosives.

Recently these systems have been employed in areas where high impulse liquid or solid propellant units are stowed and where burning of such a unit might constitute the source of a conflagration. Only recently has the sprinkler system been considered as a means of subduing such a fire or a means of prevention of chain ignitions of other units subjected to exhaust gas impingement.

Fortunately, it has been possible to obtain some information concerning the value of a sprinkler system under this expanded concept, since such systems have been employed during the course of missile magazine hazards investigations conducted at the Naval Weapons Laboratory, Dahlgren. These investigations have provided the most realistic evaluation of the two systems

to date under the environment produced by burning of missile propulsion units. The environment produced by the burning of missile propulsion units differs from that produced by a common fire in the same or an adjacent compartment in several respects, as follows:

> The rate of temperature rise may be significantly greater; the burning produces a significant pressure increase within the compartment and extremely high pressures may exist in localized areas; and high velocity, very high temperature gases are present.

The magazine hazard investigations conducted have indicated a need for improvement of the systems and system hardware and have indicated certain operational deficiencies and peculiarities.

In general, the tests have indicated that a shorter actuation time is necessary and that the system must be made more reliable. One means of reducing actuation time is through pre-filling of all sprinkler lines from the main control valve to the sprinkler heads. Maintaining filled lines under all conditions of ship shock, roll, and vibration, is considered a major problem. It is considered that an increase in reliability may be attained through improvement of the detection system, possibly employing a principle other than the present thermo-pneumatic system. A sprinkler system actuation time as low as 1 to 2 seconds is considered necessary. Times of 10 to 20 seconds are now common.

While the sprinkler system in itself may not be expected to extinguish the solid propellant of larger missiles, it can play a significant part in the prevention of chain ignitions by cook-off through the cooling of exhaust gases and adjacent motor cases. In tests conducted, a sufficiently fast sprinkler system has, under proper conditions, extinguished the burning of nonpropulsive, solid propellant air launched missiles where the motor case has been eroded through, exposing the grain to sprinkler action. A modified version of the sprinkler system which we call the "deluge" system is designed specifically to cool exhaust gases through entrainment of large quantities of water in the exhaust gas stream(s). Although proven effective, these systems are not being considered where the normal sprinkler system will suffice.

Water injection is a means of applying water directly to the burning propellant of a motor through the nozzle opening of the motor. Burning is diminished, or extinguished, through cooling of the propellant. Relatively large quantities of water are needed to be effective, particularly in view of the inefficiencies in applying water to the entire

burning area of the grain. Water injection is now being employed only for nonpropulsive burnings where the motor is assembled to be nonpropulsive or where motor rupture occurs; however, its use in the future for fully propulsive units is being considered. Significantly higher water pressures are indicated for propulsive usage.

A water injection system should meet the following requirements: (1) the supply of water must be adequate, (2) application of water must commence while motor pressure is still low (in order that the motor pressure does not, or will not exceed the water injection pressure), and (3) the system must be compatible with the grain configuration, the magazine and the motor hardware. Such factors as the number, size and spacing of grain perforations, the characteristics of seals in the motor nozzle, the diameter of the motor nozzle, and the response time of the water supply pumps must all be considered in developing such a system.

Water injection is now being employed for the Mk 13 and Mk 11 TARTAR systems in DDG and DLG destroyer class ships and for TERRIER booster stowage in the Mk 10 system magazine aboard DLG and CGN class ships. A typical water injection system is shown schematically in slide No. 9.

The heart of the water injection system is the detector. The detector must be selective to the extent that it will respond only to the ignition of its respective motor. It must be relatively insensitive to mechanical shock, be unaffected by salt water and meet numerous other requirements.

The detector now being installed in TARTAR and TERRIER systems is blast actuated and water pressure powered. It was developed by the Naval Weapons Laboratory and serves a three-fold purpose: (1) it senses that a motor has ignited, (2) it acts as a valve to permit water flow, and (3) it acts as a nozzle to direct the water into the motor through the motor nozzle. An assembled view of this detector is shown in slide No. 10.

The normal operating time for this detector, to initiation of water flow, is 3 to 4 milliseconds. This detector will actuate on blast pressures as small as 11 psi when the water pressures is as high as 200 psi.

Flame impingement on the grain of adjacent motors may be prevented by various techniques and systems including positioning of motors with respect to each other to prevent impingement on vulnerable areas, nozzle and igniter closures and covers, shipping containers, and flame shields. It has been determined to be advisable to avoid perpendicular arrangements unless flame shields can be provided. Flame shields are portable bulkheads

placed at strategic positions between motors to deflect high velocity gases. They must remain in place and resist erosion by the gases under severe heat and blast conditions. Promising ablating materials have been developed recently permitting substantial savings in the weight of flame shields. Included among the more promising materials are the room temperature vulcanizing silicone rubbers, the chopped asbestos filled phenolics and silica fiber phenolic laminates.

Typical igniter and nozzle opening closures for the SPARROW missile are shown in slide No. 11, while an igniter end cover and a nozzle closure for the TALOS booster are shown in slide No. 12. These items are installed upon assembly of the motor and may be removed prior to assembly of the missile for ready service stowage. A ready service nozzle closure for the TALSO missile is shown attached to a ready service tray in slide No. 13. These closures do not require removal of the moisture seals installed by the loading plant.

Shipping containers are normally employed in some stage of the logistic history of a missile, and, if made of heat resistant metal, these normally serve the same purpose as the nozzle and igniter closures and flame shields.

Magazine venting provides a method of maintaining the temperature and pressure environment during an accidental burning at a level that will permit control of chain ignitions. Provision of adequate vents and venting ducts in some ships, particularly where magazines are located deep in the ship is a problem because of space limitations. A concept now being advocated is to let magazines vent into uninhabited, inert stowage areas when adequate ducting cannot be provided. The venting area required to maintain pressures below bulkhead strength limits has been determined to be, within practical magazine volume limits, dependent only on the mass rate of discharge of the burning motor(s). A simple emperical relation has been developed for determining this vent area.

A plenum chamber is a special form of venting. A plenum chamber is normally used to duct the exhaust gases of a propulsive motor to the atmosphere without allowing the gases to pass through the magazine, and around expensive equipment or other explosive and propellant components. A typical plenum chamber and duct system is shown in slide no. 14. Chain ignition by means of gas flow through the plenum chamber itself is prevented by means of unidirectional displacement plates, one behind each motor.

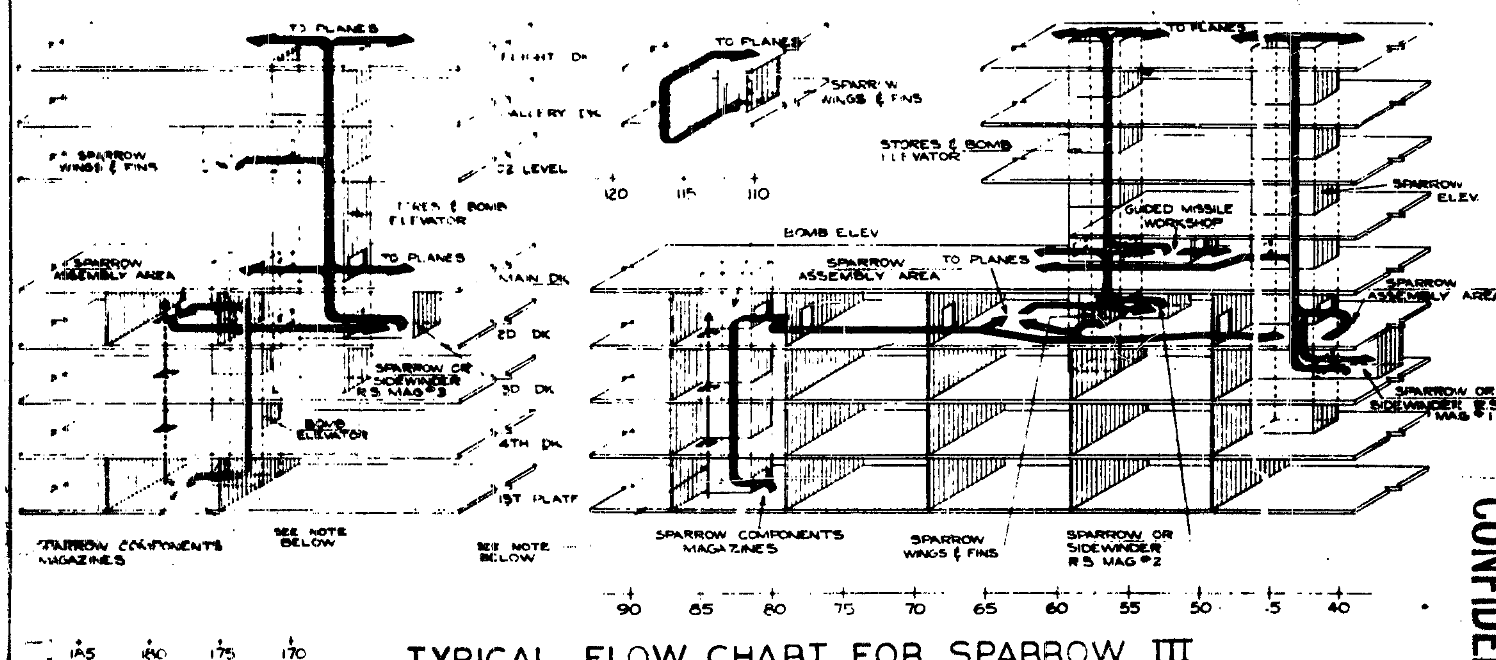
Segregated stowage of missiles containing unlike propellants is the accepted "rule of thumb" until evaluations indicate that no additional hazards are introduced through integrated stowage. Integrated stowage is, at times, desirable since it simplifies logistic and operational problems. Recent tests have, for example, indicated the possibility of safe stowage of BULLPUP A liquid and solid propellant units in the same magazine.

The restraint of motors during accidental burning is an important aspect in the control of chain ignitions, since most control systems are designed to control burnings of stationary motors. If motors are not restrained, additional ignitions may be induced through impacts with other motors and destruction of safety systems. Various methods are employed to assure restraint of missiles.

Slide No. 15 shows the use of restrainer bars, designed to hold a TALOS booster against its full propulsive thrust. These bars are attached to the booster shoes at one end and to a fixed bulkhead at the other. Special efforts were necessary during development to assure that the bars would resist the erosive effects of the booster exhaust gases.

Assembling motors so that they will be nonpropulsive during stowage and handling is another method of restraining motors. This may be done by providing a thrust neutralizer as shown in Slide No. 16 or, if the motor is so designed, by providing for venting through the igniter opening at the forward end. Each of these methods may produce an effective cancellation of the normal propulsive thrust, hence the motors may be held in place by structural hardware that would not normally restrain a fully propulsive unit.

Through planned combinations of the safety systems discussed in many installations, the likelihood of chain ignition has been significantly reduced. Employment of these systems may ultimately save lives and ships without being prohibitive from a cost or space standpoint. The employment of these systems represent another step in the evolutionary process of making missiles safer to employ while at the same time retaining their effective potency.



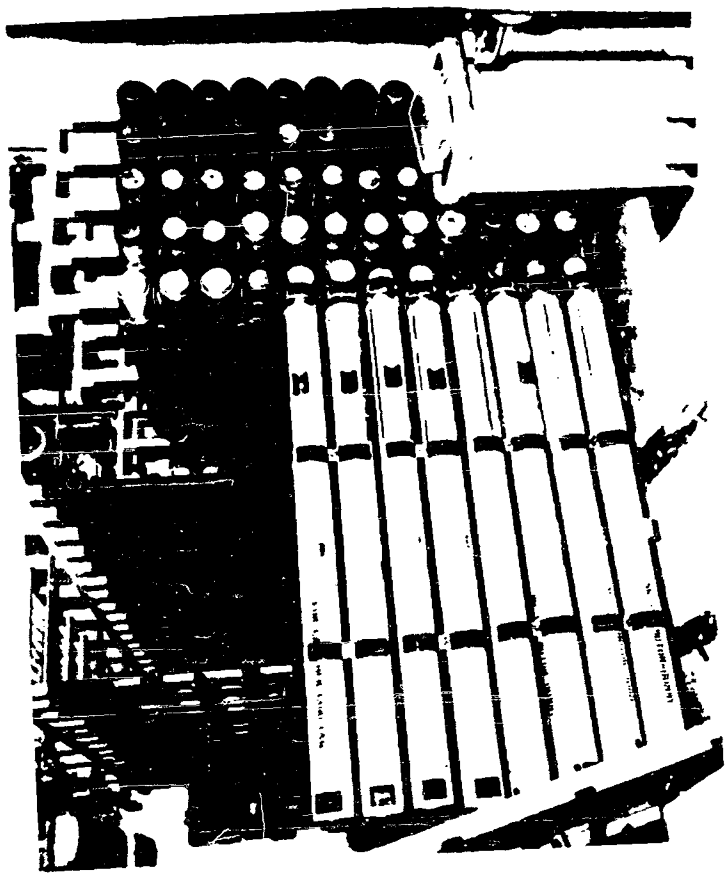
TYPICAL FLOW CHART FOR SPARROW III

CVA 59 & CVA 60

SHOWING EXTENSIVE ROUTING OF

COMPONENTS THROUGHOUT SHIP

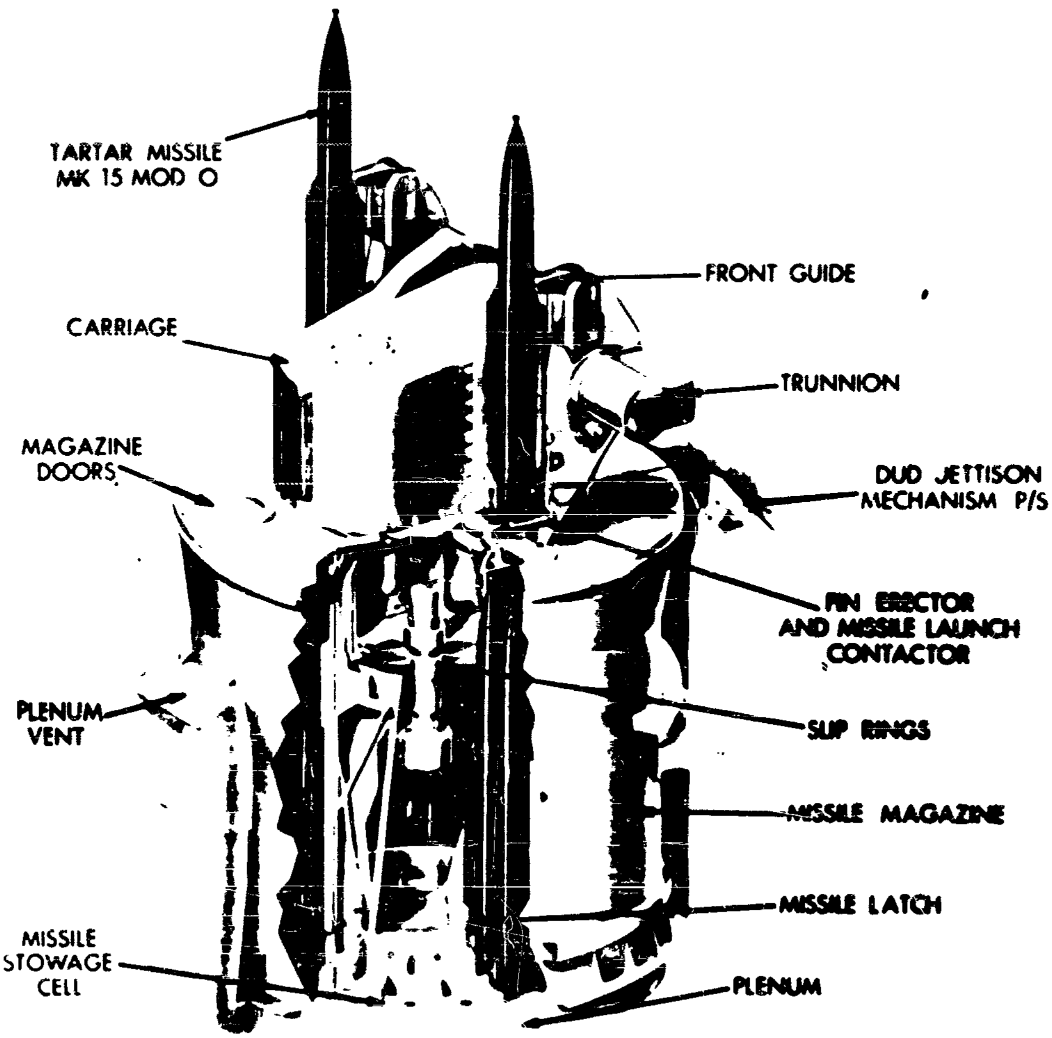
Slide 1



TYPICAL MAGAZINE ARRANGEMENT SHOWING
DENSE STOWAGE OF SIDEWINDER MOTORS

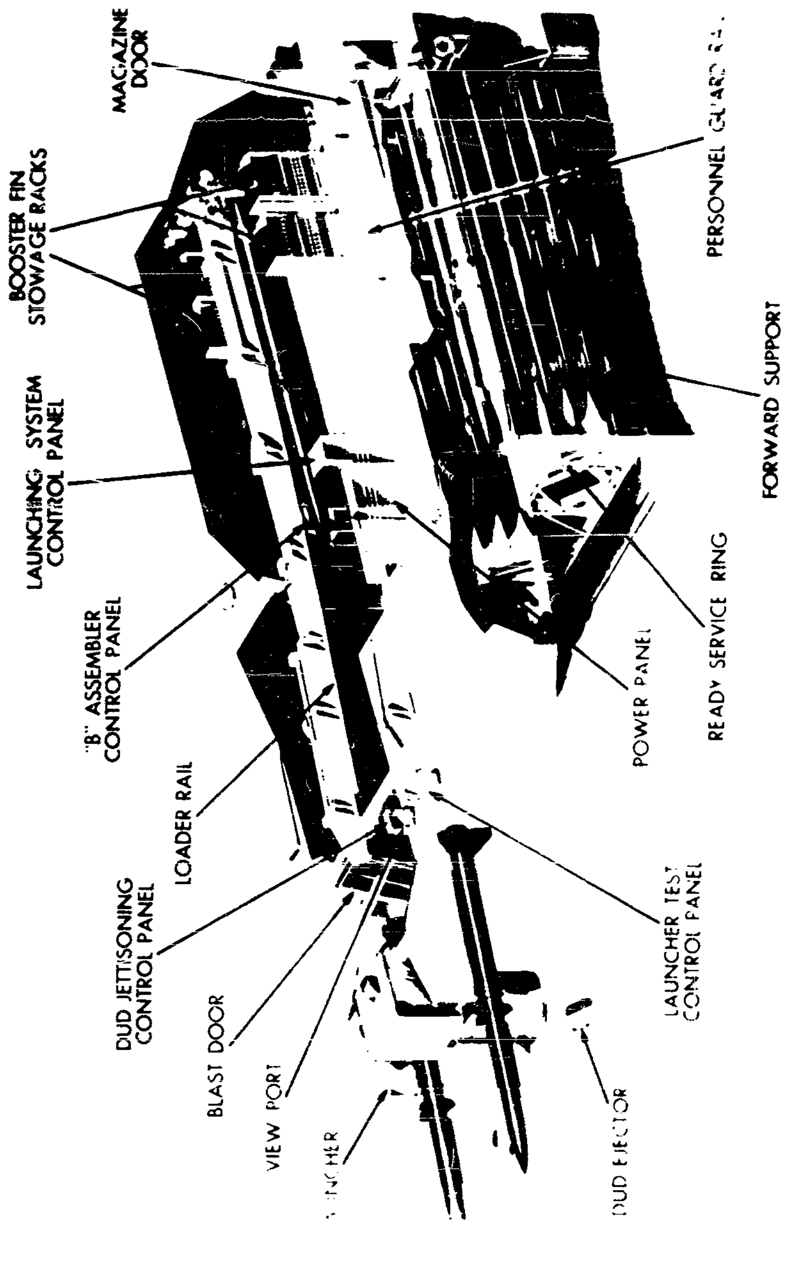
CONFIDENTIAL

Slide 2



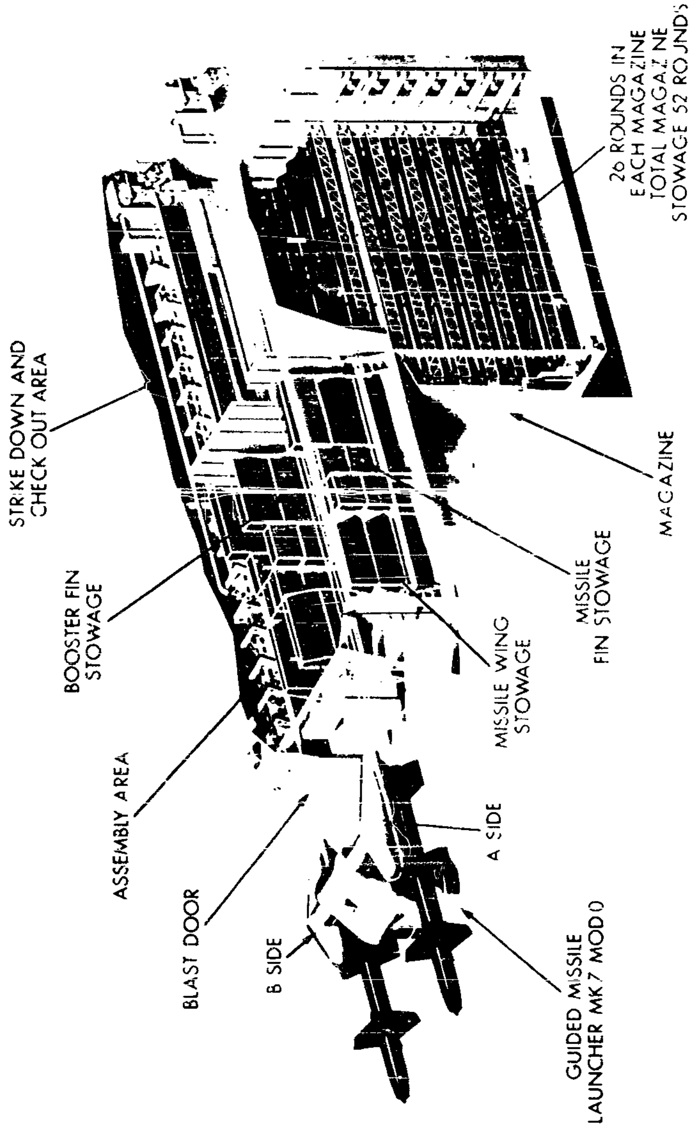
Slide 3

TYPICAL TARTAR READY SERVICE MAGAZINE



TYPICAL TERRIER READY SERVICE MAGAZINE

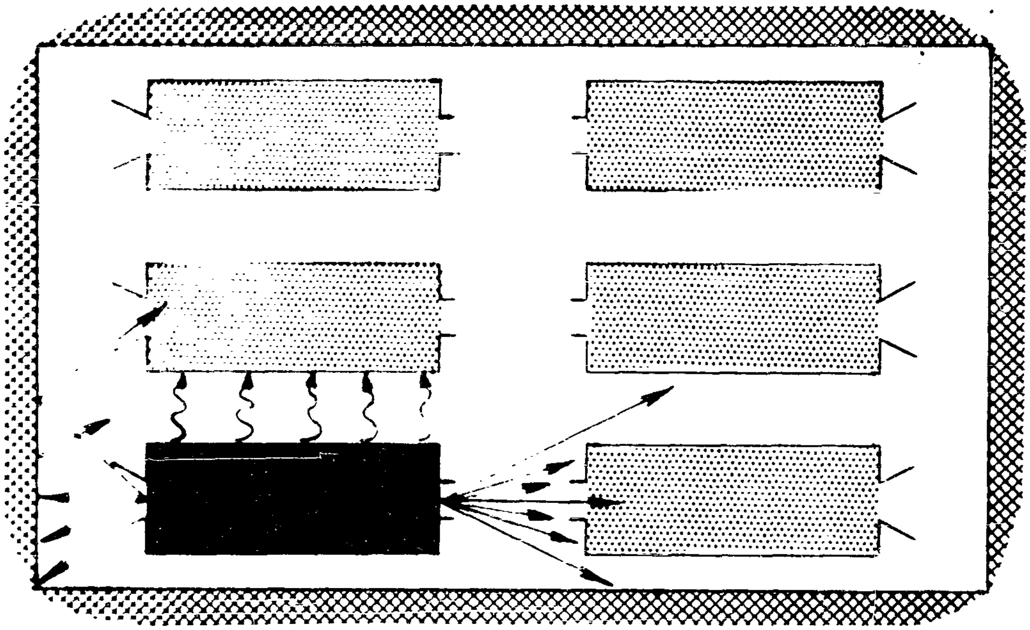
Slide 4



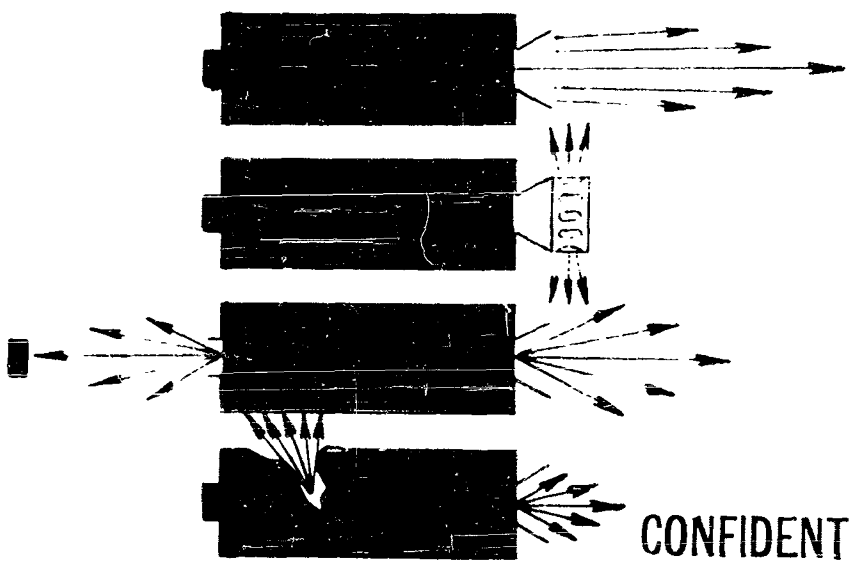
TYPICAL TALOS READY SERVICE MAGAZINE

Slide 5

CONFIDENTIAL



COMMON CHAIN IGNITION PROCESSES



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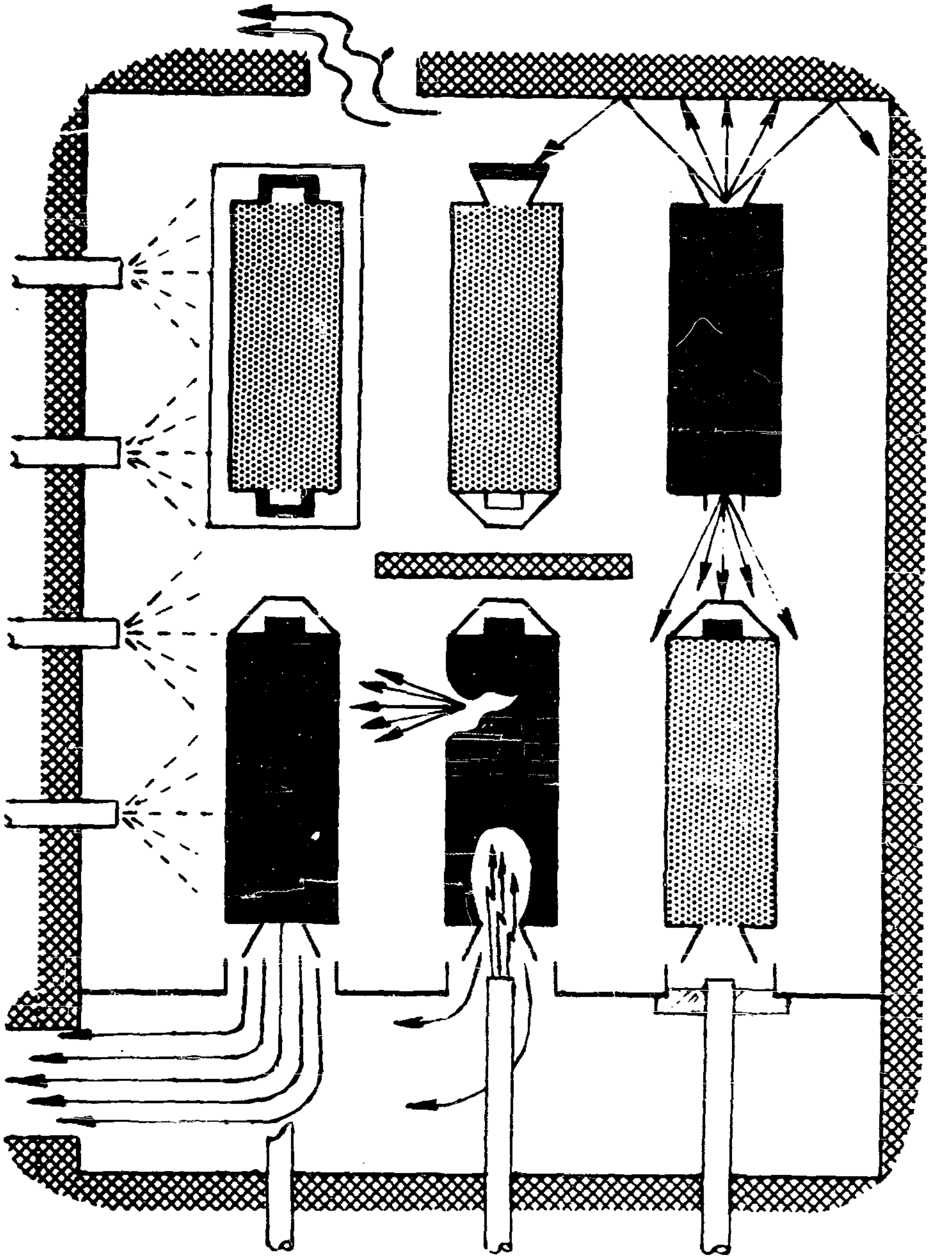
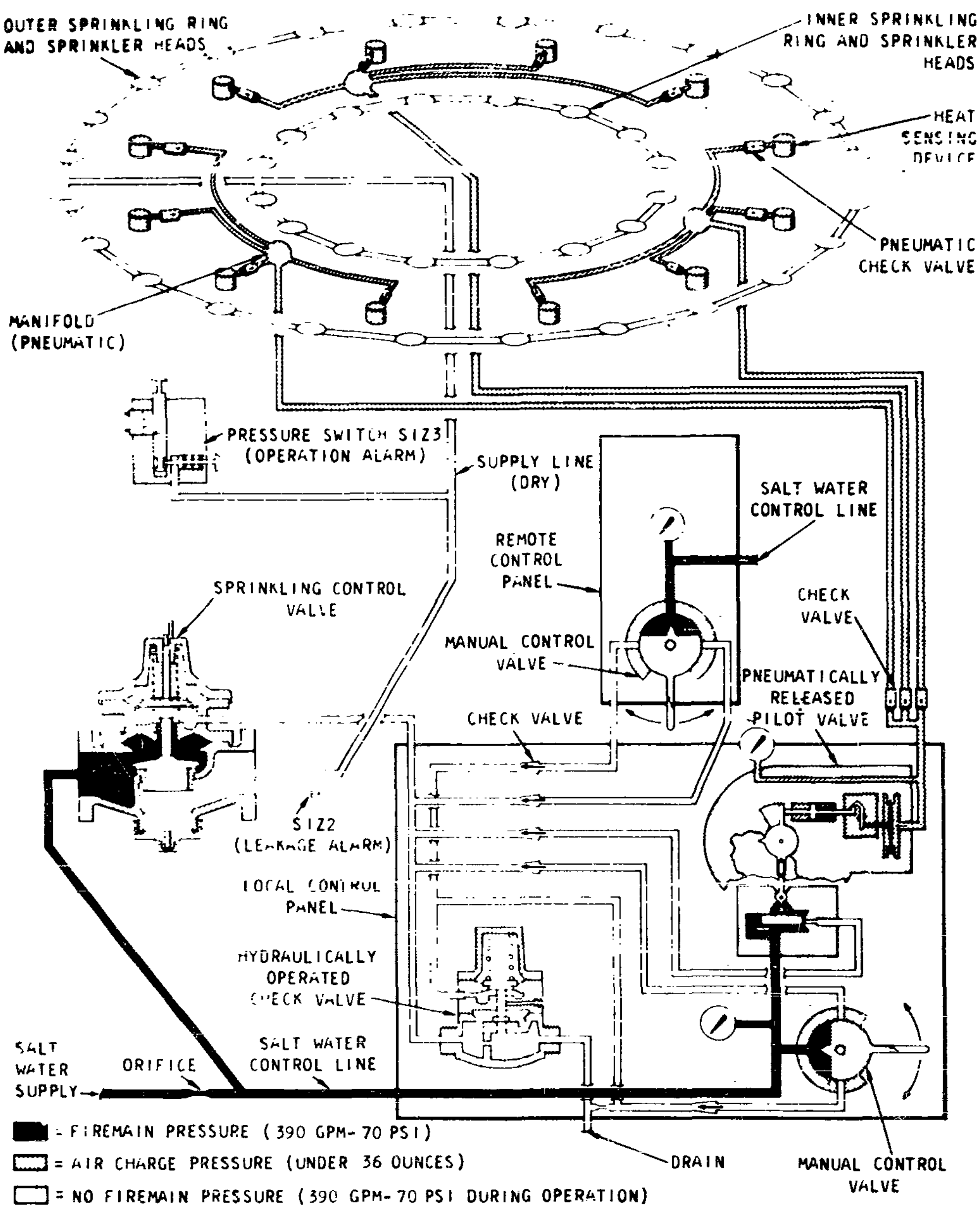
Slide 6

PROPULSIVE AND NON-PROPULSIVE BURNING



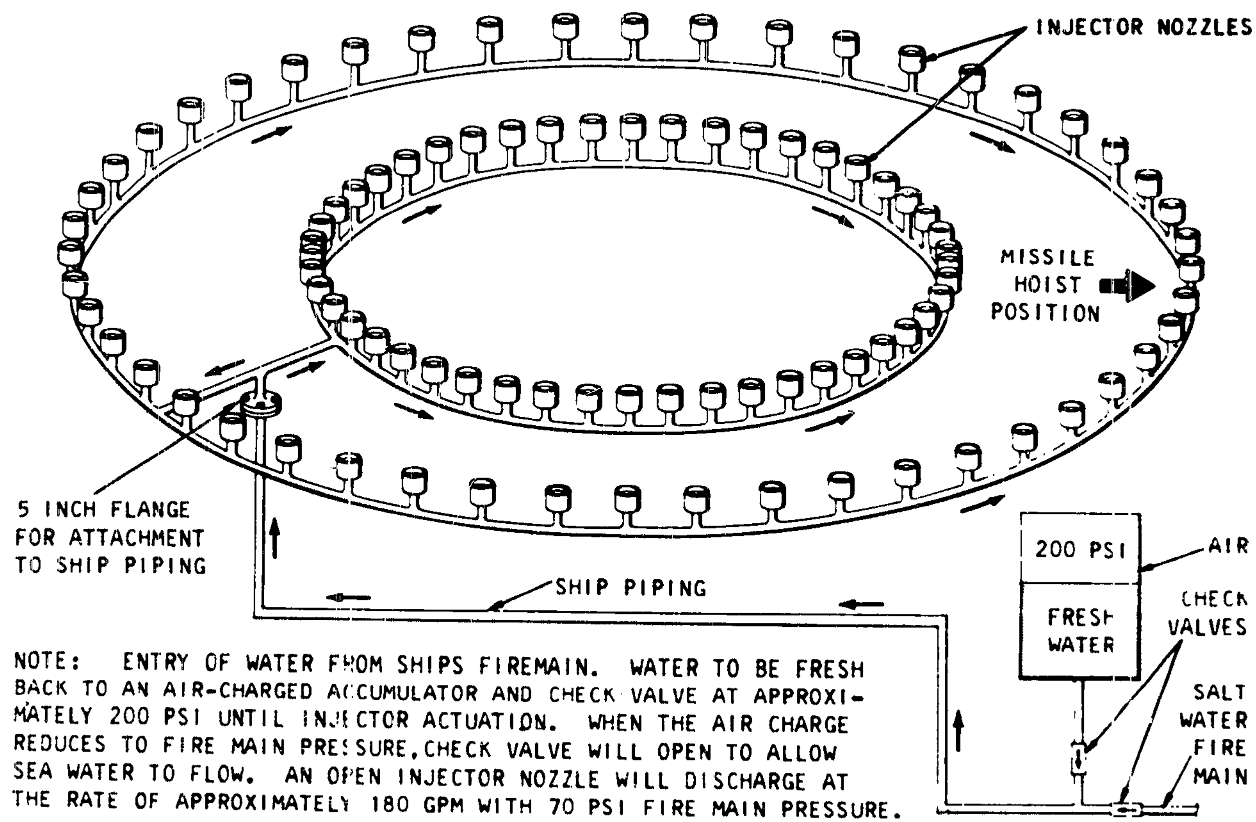
Slide 7

REPRESENTATIVE SAFETY SYSTEMS



Slide 8

TYPICAL SPRINKLER SYSTEM

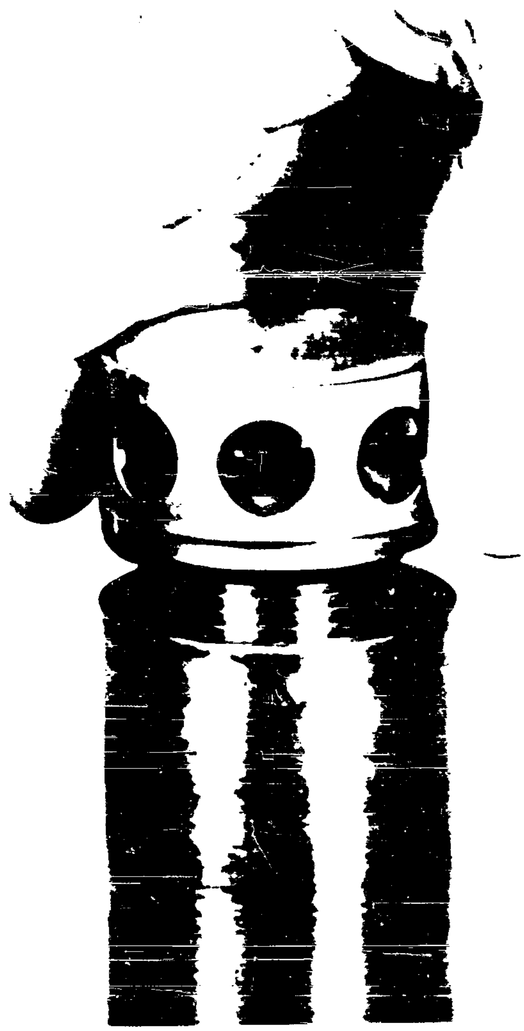


NOTE: ENTRY OF WATER FROM SHIPS FIREMAIN. WATER TO BE FRESH BACK TO AN AIR-CHARGED ACCUMULATOR AND CHECK VALVE AT APPROXIMATELY 200 PSI UNTIL INJECTOR ACTUATION. WHEN THE AIR CHARGE REDUCES TO FIRE MAIN PRESSURE, CHECK VALVE WILL OPEN TO ALLOW SEA WATER TO FLOW. AN OPEN INJECTOR NOZZLE WILL DISCHARGE AT THE RATE OF APPROXIMATELY 180 GPM WITH 70 PSI FIRE MAIN PRESSURE.

WATER INJECTION SYSTEM SCHEMATIC

Slide 9

CONFIDENTIAL MODIFIED HANDLING AUTHORIZED



INJECTION SYSTEM DETECTOR

Slide 10

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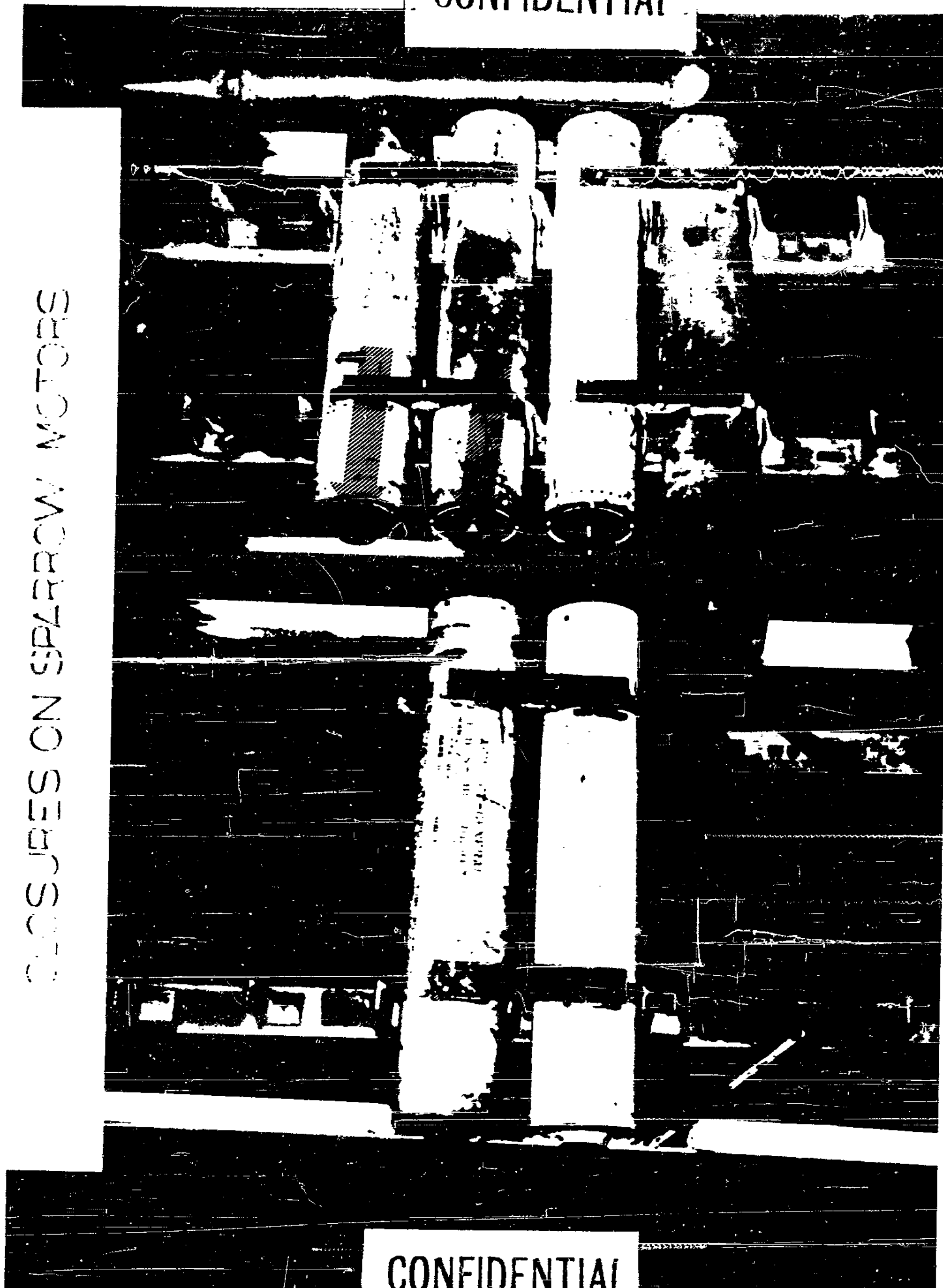

CLOSURES ON SPARROW MOTORS

Slide 11

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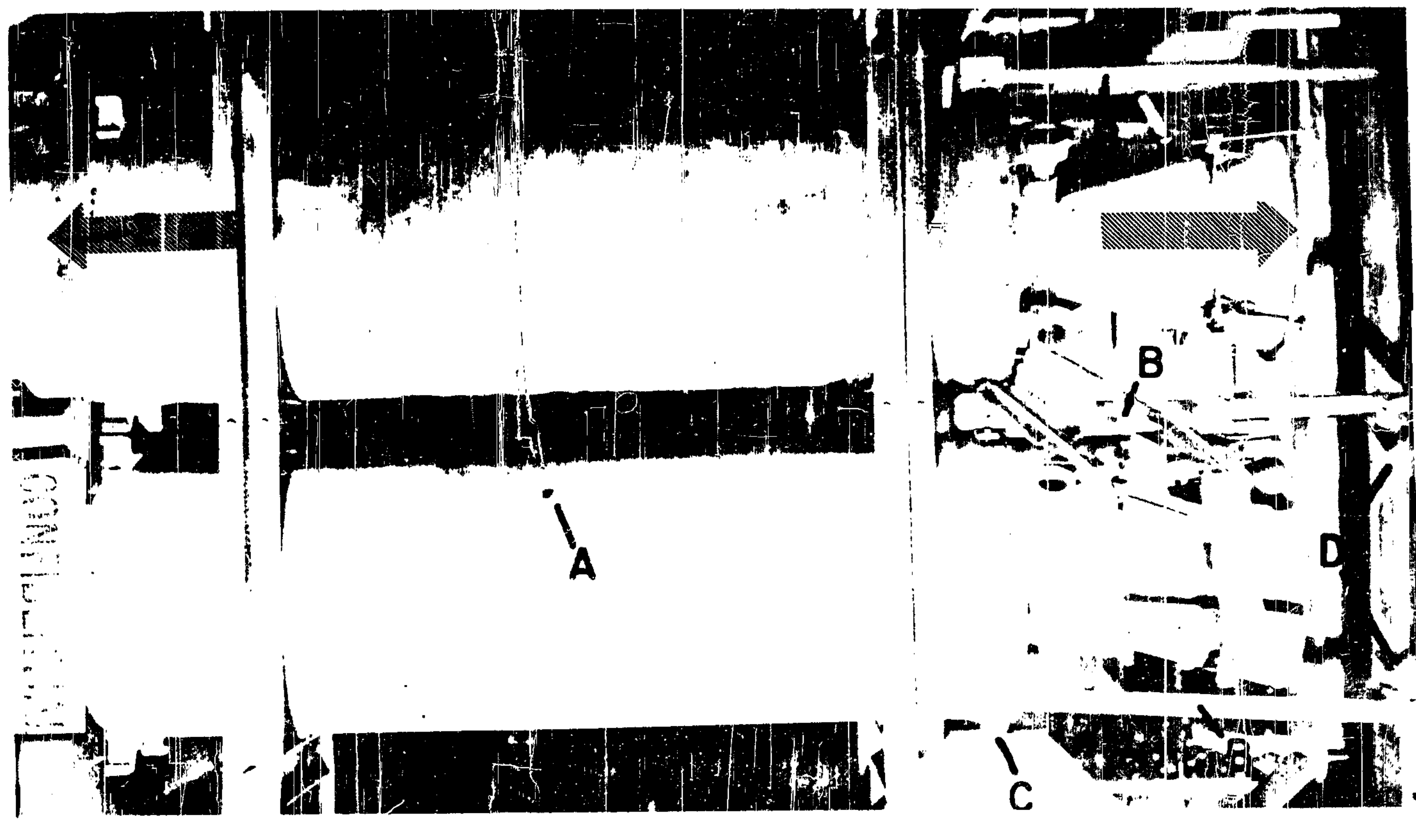
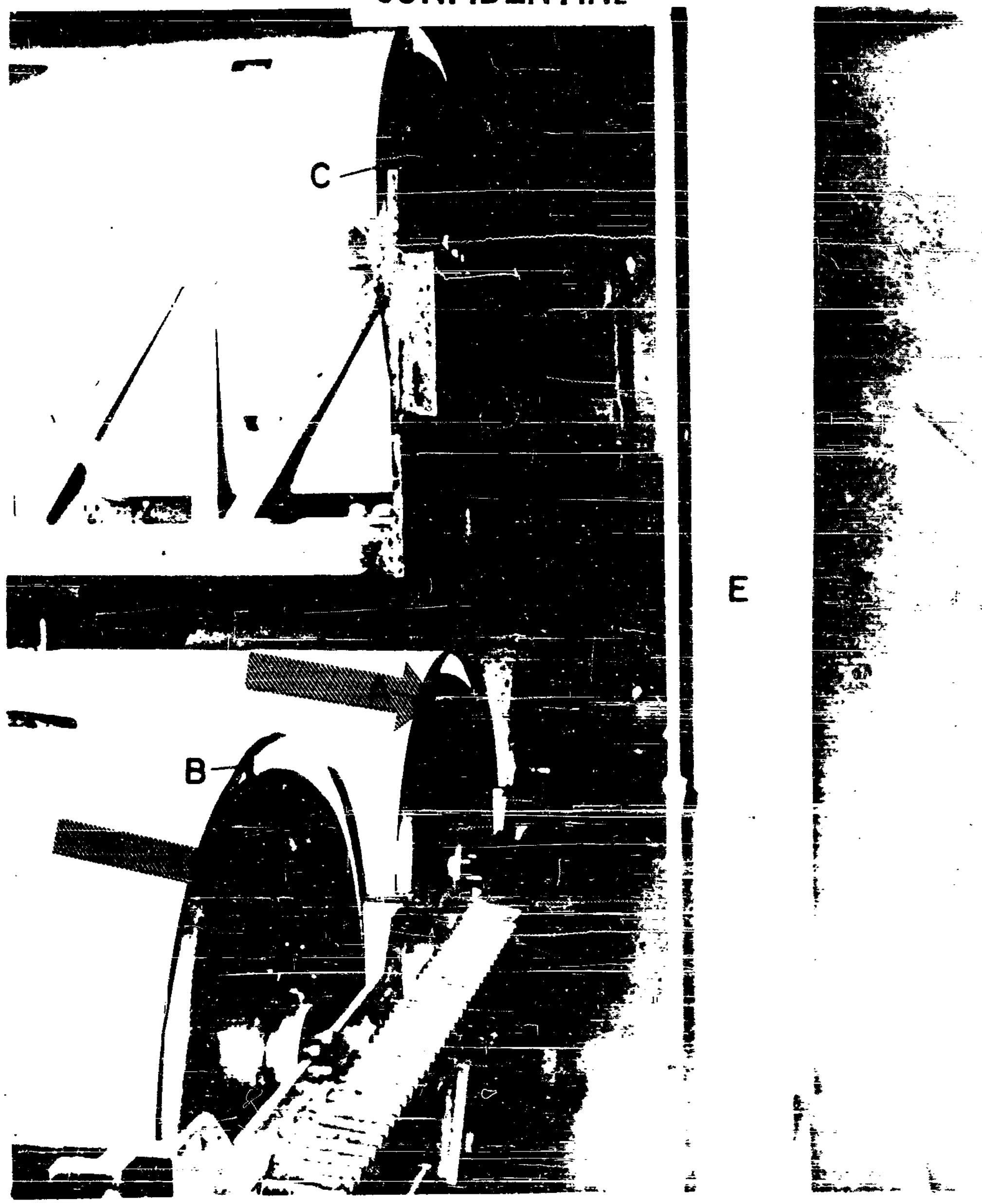


NOZZLE CLOSURE AND IGNITER

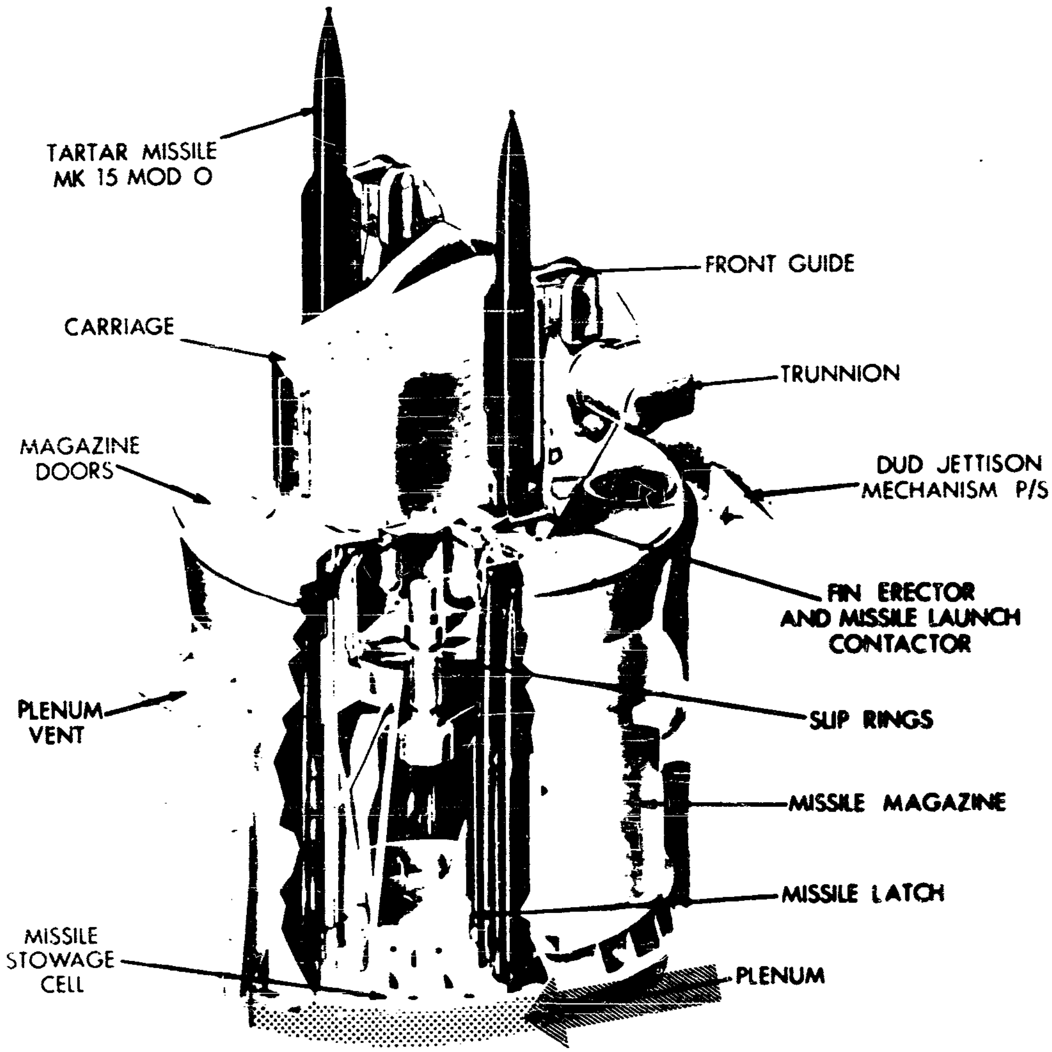
COVER AFTER TEST

Slide 12



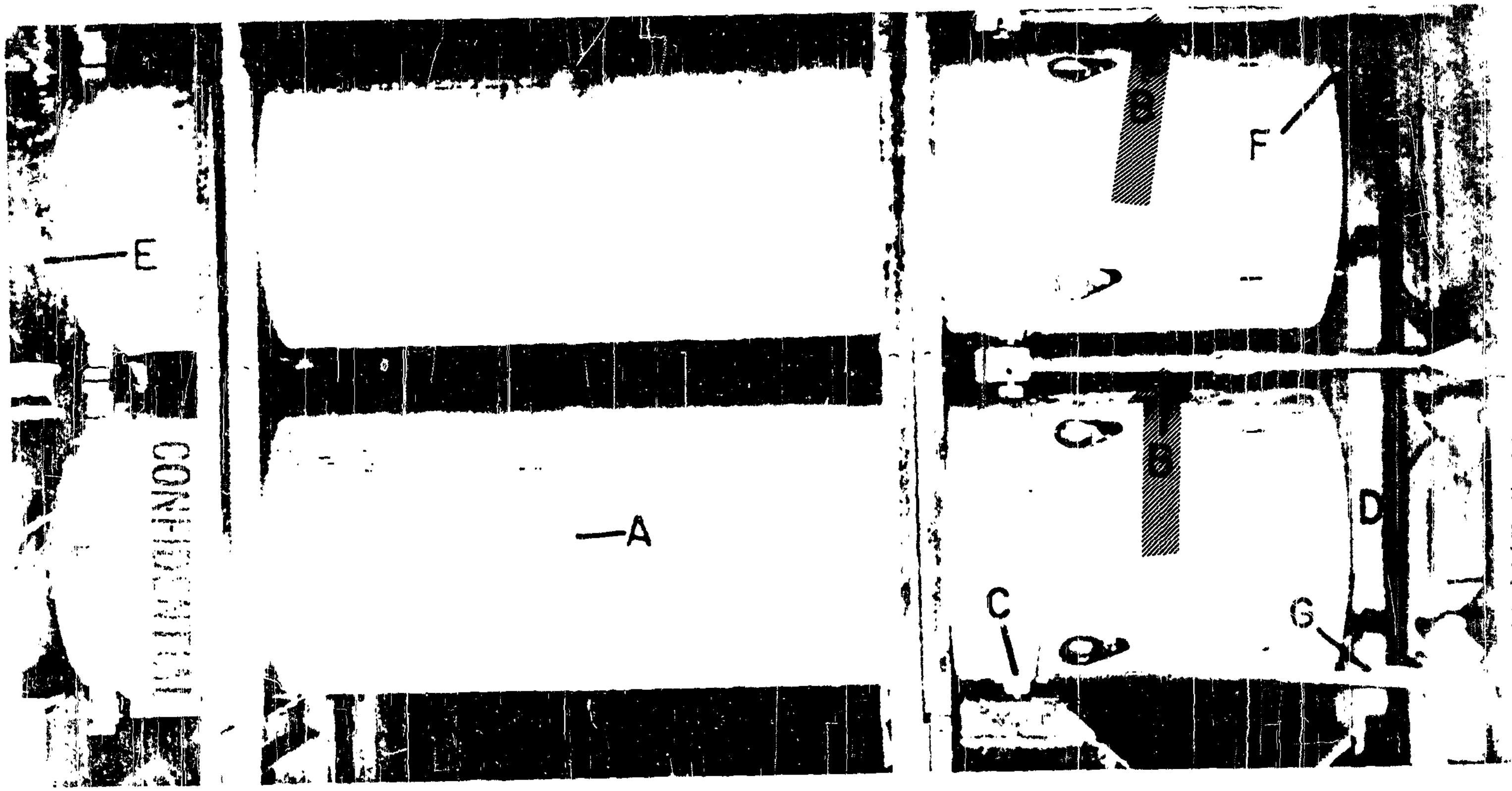
TRAY CLOSURES INSTALLED F

Slide 13



Slide 14

TYPICAL PLENUM CHAMBER



RESTRAINER BARS IN USE

FOR BOOSTER STOWAGE TEST

Slide 15

CONFIDENTIAL

Slide 16

AN INVESTIGATION OF QUANTITY-DISTANCE RELATIONSHIPS FOR SILO TYPE LAUNCH SITES

by

Thomas H. Pratt

Rohm & Haas Company
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Introduction

The Rohm & Haas Company, Redstone Arsenal Research Division, has been carrying out an investigation concerning the possible utilization of a plastisol nitrocellulose propellant formulation for the Nike Zeus missile system. This particular formulation has one characteristic in common with most proposed high energy propellant formulations - the critical diameter for high order detonation is exceeded by the missile configuration and there is a possibility of detonation of such systems. In January of 1962, this Division was asked to consider tests which would determine if the detonation characteristics of this (or other high energy systems) would preclude their use in planned missile firing configurations by offering sympathetic detonation probability from launch cell to launch cell in the next system proposed. After discussion with the interested parties, it was decided that a useful test could be made in scale. The design and interpretation of tests were to be conducted by Rohm & Haas but the actual testing would be carried out by the Test and Evaluation Laboratory, Research and Development Operations of the U. S. Army Ordnance Missile Command.

The proposed layout for the underground firing sites is to place four cells 17.5' apart in a square array. The cells have one foot reinforced concrete walls with inside dimensions of 9' square. A 6'x9' stack is provided for exhaust gases and is separated from the main cell by a one foot reinforced concrete wall. Such an array of four cells is termed a "nest"; an internest distance of 100' is proposed. The number of nests per site is yet to be determined.

The basic concept to be tested was whether sympathetic detonation of a high energy propellant was possible at the intercell spacing proposed for a Nike Zeus launch site. Since the formulation being developed at Rohm & Haas has been

experimentally demonstrated to have a rather low sensitivity (relatively insensitive) by the standard card gap methods, it was decided to use the most sensitive material practical for the acceptor in the proposed tests. As tetryl is used in most warheads as a booster and is considerably more sensitive than any of the propellants being developed, as well as being readily available in proper shape and size, it was selected for the program. A very basic point in the tests was to determine if, in fact, a high explosive in a missile configuration yielded the same distribution of energy as would the same material initiated from the center of a spherical charge of the same mass. Considerable work had been done on the cratering effect of high explosives submerged in the ground.[1] The cratering effect is a measure of the available energy from detonation. However, limited data on hydrodynamic scaling indicated that the laterally transmitted impulse might be a function of diameter rather than total mass. Using this hypothesis, a series of firings was laid out to determine the effective scaling law for sympathetic detonation under these conditions.

From the outset of the program, it was realized that an extrapolation from subscale tests to the full size missile is open to criticism. However, tests in-scale seem to be the most reasonable approach in the interest of economy of time and materials. In several instances, exact scaling has not been adhered to. However, a policy of selecting the worst conditions in terms of detonability was used whenever compromises were made.

[1] Fundamentals of Protective Design, U. S. Army Corps of Engineers, Manual 1110-345-405, 1946

EXPERIMENTAL ARRANGEMENTS

It was decided to perform seven tests: three at 0.1 scale, two at 0.2 scale, and two at 0.3 scale. These were numbered one through seven respectively. The first 0.1 scale test was performed as a familiarization experiment and the last 0.3 scale test was used to determine any additional parameters which were deemed necessary in the course of the program.

The scaling law used in setting up the tests was that, at a scale of s, all linear measurements were s times the corresponding dimension of the full scale item. Since the mass of an object varies as the cube of its linear dimensions, the scaling law of the test charge becomes

$$W_s = Ws^3 \tag{1}$$

where W_s is the mass of the test charge at scale s and W is the mass of propellant in the full scale missile. For reasons of economy, perforated charges have not been used. The charges were right circular cylinders which have been poured and cured in either wax coated pasteboard containers or fabricated polyethylene containers. In order to facilitate the casting of these charges, the booster, sustainer, and jethead were scaled and poured separately. The masses of the charges were in keeping with Eq. 1. The aspect ratio (L/D) of each segment approximated that of the full scale missile.(see Table I).

The scaling of the cell dimensions was on the above mentioned linear basis except that the cells were round instead of square. This was done because of the ready availability of concrete pipe. Since concrete pipe was not available in a size approximating the 0.1 scale cells, Transite® pipe was used in this case. The scale sizes and actual sizes used are given in Table I. In Tests 1 through 4, the

depth of the cell was such that the top of the initiating charge was at ground level. This procedure was questioned later since the warhead of the missile is significantly below ground level. Therefore, the cells were made deeper in subsequent tests. See Figure 8 for the arrangement of a typical shot.

In Test 7 three cells were constructed to obtain supplementary information (see Figure 7). The central cell contained the scaled charge. The second cell was at a distance of 61 inches which corresponds to the proposed intercell separation of 17.5 feet. A 6C3-11.5 STM containing Composition 112 propellant was placed in this cell to obtain some estimate of the ignition hazard of missiles placed at this distance. The third cell was at a distance of 30 feet, which corresponds to the proposed inter-nest separation of 100 feet. This was done to obtain some estimate of internest damage resulting from a detonation.

The maximum distance at which sympathetic detonation will occur was assessed by placing Tetryl acceptors at varying distances from each shot. The Tetryl was placed in the earth according to the layouts given in Figures 1 through 7. The acceptors were separated from each other by a distance which was adequate to prevent sympathetic detonation between them. In separate experiments, it was determined that a dirt gap of one inch was adequate to prevent sympathetic detonation for the size of Tetryl pellets used (7/8" diameter by 1" long).

The acceptors were constructed by taping a stack of pellets onto a one inch diameter aluminum witness rod. The acceptors extended to the same depth as the scaled cell; however, in some instances the acceptor charges were segmented rather than continuous (cf. Table II). A two inch hole was bored into the ground of the proper depth and at the desired separation distance according to the schedule presented in Figures 1 through 7. After the acceptor was positioned, sand was poured

into the remaining voids. This places the acceptor in a somewhat continuous medium of packed earth.

In Test 1, wood witness dowels were used but were not recovered intact after the shot. Some small splinters were recovered, but it was impossible to assess from these if detonation had occurred. In subsequent tests the aluminum rods were used. In Test 2, only four of the six rods used were recovered; the remaining two were thrown into an adjacent swampy area by the blast. In the remaining tests, a long length of steel cable was fastened to the rod and laid out on the ground radially from the shot. This decreased the throw-distance of the witness rods and greatly facilitated recovery. In most instances, the occurrence of sympathetic detonation in the acceptors was evident from the condition of the witness rods. The rods were flattened and well etched. In some cases, a degree of etching occurred without significant flattening, making interpretation difficult. In those cases where doubt existed, the acceptors were termed "go" rather than "no go."

For sympathetic detonation to occur in the full scale missile, the shock wave from the initiating detonation in the adjacent cell must pass through an air gap in order to reach the acceptor missile.

Besides primary shock wave initiation, a second mechanism is also possible - the impinging of high velocity concrete fragments from the containing wall against the missile. It was assumed that the maximum energy which could be imparted to the acceptor would be equal to or less than the energy transmitted through contacting earth around the acceptor. For this reason no scaled air gap was provided since this provided the maximum safety in extrapolation of test results.

The effect of an air gap was assessed, however, in Test 7 by placing four

acceptors in a 5-inch diameter hole lined with 4-inch I.D. concrete pipe. These acceptors were placed at a distance which caused sympathetic detonation in Test 6 with earth contact. Two of these acceptors were confined in copper tubing while the remaining two were unconfined - all were aligned centrally in the hole.

Detonations were initiated in the scaled charges by a 1.5-inch diameter x 4.5-inch long Composition C-4 charge packed to a density of 1.59 g/cm^3. The critical diameter of Composition 112 used in the test charges is $\leqq$ 1.15 inches, making it necessary to have an initiating charge of at least this diameter. The same size initiating charge was used in all of the tests and approximates a point initiation in the 0.3 scale tests. An "Engineers Special" blasting cap was used to initiate the Composition C-4 charge. The shot was fired by a programmed firing circuit which placed 130 volts on the blasting cap 15 seconds after a 400 frame/second 16mm motion picture camera was started. The shots were recorded on color film for possible documentary purposes.

RESULTS

After the shot was fired, the witness rods were assessed for sympathetic detonation of the Tetryl acceptors. The results are recorded in Table III where the symbol G stands for a "go" and the symbol N stands for a "no go." Table IV gives the apparent crater diameter, c_s, the apparent crater depth, h_s, and the disturbed earth diameter, e_s. The disturbed earth diameter, e_s, is taken to be the diameter of the region of earth which definitely exhibits voids and/or cracks. The earth is actually disturbed to a greater extent than measured by e_s in that it has suffered a permanent radial displacement; however, a measure of this

larger diameter would be difficult to ascertain reproducibly. Figure 9 compares the crater diameter to the proposed layout of the launch complex.

In Test 7, depth profiles of the particle density, ρ_p, and bulk density, ρ_b, were determined in the excavation for the shot before it was lined with concrete. The samples were taken with a core borer. The bulk and particle densities are recorded in Table V, and plotted in Figure 10. This Figure also contains other pertinent depths for comparison purposes.

The test motor which was in the scaled 17.5 foot cell in Test 7 was located in the crater after the shot. The case of the motor, which was much thicker than scale, was extensively deformed by the blast. The propellant in the motor did not detonate but ignited and burned for some time after it came to rest near the surface of the resulting crater, as evidenced by aluminum oxide deposition on the fresh surface.

The cell which was placed at a scaled distance of 100 feet in Test 7 suffered a deformation and a longitudinal cracking in the top section of the reinforced concrete pipe simulating the cell.

The 400 frame/second motion pictures of the tests provided the following data: 1) the height of the fireball; 2) the diameter of the fireball; 3) the angle of attack of the earth as it was blown free. These data are given in Table VI. It is interesting to note that the angle of attack of the debris is some 75° in the scale tests. A linear extrapolation to full scale for the fireball dimensions yields a height of 425' and a diameter of 200'.

DISCUSSION OF RESULTS

The extrapolation of the subscale data to full scale requires a theoretical justification for the functional form of the extrapolation used. A reasonable "worst condition" extrapolation can be made from considerations based on scale theory and empirical data using the functional form of impulse for the extrapolation.

By way of definition, one may write the following scale factor relationships.

$$r_s = sr$$
$$U_s = \phi U$$
$$t_s = \tau t$$
$$p_s = \pi p$$
$$E_s = \epsilon E$$
$$I_s = \psi I$$

where s, ϕ, τ, π, ϵ and ψ are the scale factors for the distance r, velocity U, time t, pressure p, energy E, and impulse I respectively. The subscript s refers to the quantity in scale while the full scale quantities have no subscript.

A dimensional analysis yields the following relationships between the scale factors

$$\phi = \frac{s}{\tau}$$
$$\pi = \rho\phi^2$$
$$\epsilon = \pi s^3$$
$$\psi = \rho\phi^2\tau$$

In field tests the velocity scale factor ϕ and the density scale factor ρ are necessarily unity since the sound velocity and density are constant and do not vary

with scale. This being the case, the following numerical relationships between the scale factors are apparent.

$$\tau = s$$

$$\pi = 1$$

$$\epsilon = s^3$$

$$\psi = s$$

This type of scaling is known as Mach's similitude from which the familiar cube root scaling law is a necessary consequence, i.e.,

$$s = \left(\frac{W_s}{W}\right)^{\frac{1}{3}} \qquad (2)$$

where W is the mass of the explosive.

A pressure-distance relationship has been determined[1] for a shallow underground explosion.

$$p = k_1\lambda^{-3} \qquad (3)$$

where λ is the radial distance from the explosion divided by the cube root of the mass of the explosive.

The impulse at a specified point in a scale explosion is given by

$$I_s = p_s a_s \qquad (4)$$

where p_s is the pressure generated at that point and a_s is time for which it acts. This assumes a decaying square wave for the pressure front which is not realistic; however, the functional form of the resulting equation will not be affected by

[1] Merrit, McBonough, Newmark, Evaluation of Data from Underground Explosion Tests in Soil, University of Illinois Report SRS #152, May, 1958

this approximation. Substituting Eq. 3 in Eq. 4 and scaling the time, we have

$$I_s = k_1 \lambda_s^{-3} sa \tag{5}$$

where a is the corresponding width of the pressure front at full scale. Substituting Eq. 2 into Eq. 5 and writing λ as a function of mass and distance, we have

$$I_s = k_1 \frac{W_s}{r_s^3} \left(\frac{W_s}{W}\right)^{\frac{1}{3}} a \tag{6}$$

If we require a critical value, I_c, for the impulse, below which sympathetic detonation will not occur at any scale, then Eq. 6 may be reduced to the form

$$I_c = k \frac{W_s^{\frac{4}{3}}}{r_s^3} \tag{7}$$

since W and a may be considered constants when I_s has a specified value.

We can now reduce Eq. 7 to the forms

$$k_3 = \frac{W_s^{\frac{4}{3}}}{g_s^3} \qquad \text{or} \qquad k_4 = \frac{W_s^{\frac{4}{3}}}{n_s^3} \tag{8}$$

for purposes of extrapolating the "go" distances, g_s, and the "no go" distances, n_s, in the scale shots.

Eq's 8 do not include any variation in the geometry of the detonating charges. It may be expected that long cylinders would give a relationship of a different form than that for spherical charges. Some evidence for this is found in Test 6 where ten-inch Tetryl acceptors were placed at the top, in the center, and at the bottom of the witness rods (see Figure 8). Different n_s and g_s values were found for the center and bottom witnesses (see Table III). The shock wave hitting the center Tetryl acceptors results from the detonation of the scaled sustainer charge, assuming that the shock wave proceeds radially from its source. This indicates that the diameters of long cylinders should be scaled, as in the case of an infinite

cylinder, rather than the masses of the scaled charges. This being the case, one should convert the mass scale given in Table I to a diameter scale presented in Table VII, along with the corresponding n_s and g_s values. In doing this, one can obtain an additional point by considering the sustainer portion of the scale charge in Test 6 as a booster at a scale of 0.25.

Since the masses of the charges vary as the cube of their diameters, Eq. 9 takes on the form

$$k_5 = \frac{d_s^4}{g_s^3} \qquad \text{and} \qquad k_6 = \frac{d_s^4}{n_s^3} \tag{9}$$

The values of n_s and g_s are determined from the data given in Table III. The n_s point is selected as the shortest distance which always yielded a "no go" - the g_s point is selected as the longest distance at which a "go" occurred. The n_s and g_s values thus selected are given in Table VII along with their corresponding diameter scale factors. A plot of these data is shown in Figure 11. This plot strongly indicates that the relationship between sympathetic detonation distance and scale is not linear but turns upward with scale. This is the case, however, with Eq's 9. The line drawn through the worst point and extended to full scale is taken from Eq's 9 and Figure 11. This extrapolation yields a sympathetic detonation distance of 19.7 feet at full scale for the case in which the acceptor charge is contained in packed earth. The scarcity of the data prohibit a more accurate em-empirical determination of a scaling law which could be used for the extrapolation. However, Eq's 9 represent the most reasonable worst condition.

It is interesting to note that empirical equations which have been determined for earth displacement resulting from shallow detonations have the same form as that of Eq. 7 and can be similarly reduced to the form of Eq's 9.

An $n_{0.3}$ of 26 inches is also plotted in Figure 11 for the acceptors with air gaps. An extrapolation of this point by Eq's 9 yields a full-scale "no go" distance of 10.6 feet. This indicates that the proposed cell separation of 17.5 feet is adequate to prevent sympathetic detonation from the incident shock wave even in soils of higher compaction than those present in these tests. This determination does not, however, rule out a contribution from the missiles in adjacent cells. The concomitent effects of a detonation will cause extensive damage and subsequent ignition of adjacent missiles. The contribution from these effects has not been assessed in this study, but the extensive damage and ignition of the adjacent motor in Test 7 shows that these contributions are serious considerations.

The cracking of the cell at the internest distance in Test 7 definitely shows that one could not expect to maintain a fireable missile at the proposed distance of 100 feet. A calculation of the permanent horizontal displacement of the earth at the internest distance from empirical data yields a figure of 6 inches, giving further credibility to the statement of a non-fireable missile at 100 feet.

DISCUSSION OF ERRORS

In several instances it was necessary to compromise availability with economy. The cells are fabricated with round concrete pipe rather than pouring concrete into constructed forms to attain a square cell. The choice of pipe from the commercial sizes available was made as close as possible to the size desired (see Table I). It is assumed that these deviations will not affect the results to any appreciable extent.

When the acceptor holes were bored there resulted a deviation from the vertical. In Test 6, it was found to result in a deviation of less than two inches at the bottom of the hole. Since this deviation is somewhat less than the error in determinations of the sympathetic detonation distances, it is considered negligible.

The density of the soil varies with depth (see Table V and Figure 10). These density variations would be expected to lead to anomalies in the sympathetic detonation distances. It would be expected that a longer distance to sympathetic detonation would be observed for a higher density soil. This observation may partially account for the fact that the sympathetic detonations distances made in the lower density soils extrapolate to lower sympathetic detonations at full scale. The scatter and scarcity of points prohibit any normalization of these points especially since density determinations were not made for each test.

It is also to be expected that strata in the earth would alter the sympathetic detonation distances. This effect should be carefully considered when using the data and extrapolations contained herein when applied to different soils. The soil in which the tests were made has been described[1] as Caplina and Capshaw loam which is a type of red clay.

SUMMARY

The conclusions which may be surmised from this study indicate that the proposed firing site for Nike Zeus missiles is not adequate for Class 9 or 10 missiles.

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[1] G. A. Swenson, Soil Survey of Madison County, Alabama, U. S. Department of Agriculture Soil Conservation Service, Series 1947, No. 3, issued February, 1958.

Sympathetic detonation will most probably not result when missiles are placed in firing cells placed 17.5 feet apart. However, a contribution from adjacent missiles of undetermined magnitude should be expected with such a spacing.

Missiles in adjacent nests where the internest separation is 100 feet will not remain fireable in the event of a catastrophic malfunction with a TNT equivalent approaching one.

TABLE I

Dimensions and Weights of Scaled Nike Zeus Charges
(lengths in inches, weights in pounds)

Cells

Scale	Cell I.D. Scale	Pipe I.D. Actual	Cell O.D. Scale	Pipe O.D. Actual	Cell Depth	Material of Pipe
1.0	108		132		720	
0.1	10.8	10.0	13.2	11.5	30	Transite®
0.2	21.6	21.5	26.4	27.0	55,70	Reinforced Concrete
0.3	32.4	30.0	39.6	37.0	102	Reinforced Concrete

Charges

Configuration	Length	Diameter	Ratio D/L	Ratio Used	$W_{1.0}$	$W_{0.1}$	$W_{0.2}$	$W_{0.3}$
Booster	158	43	1/2.72	1/3	9,370	9.7	77.6	261.9
Sustainer	140	36	1/2.57	1/3	6,740	6.7	53.2	180.9
Jethead	27	29	1/1.07	1/1	719	0.7	5.6	18.9
Total	325				17,189	17.1	136.8	461.7

Diameters

Configuration	0.1 Scale	0.1 Used	0.2 Scale	0.2 Used	0.3 Scale	0.3 Used
Booster	4.3	4.1	8.6	8.2	12.9	12.3
Sustainer	3.6	3.6	7.2	7.2	10.8	10.9
Jethead	2.9	2.5	4.8	4.9	8.7	7.4

Lengths

Configuration	0.1 Scale	0.1 Used	0.2 Scale	0.2 Used	0.3 Scale	0.3 Used
Booster	15.8	12.3	31.6	24.6	47.4	36.9
Sustainer	14.0	10.9	28.0	21.7	42.0	32.6
Jethead	2.7	2.5	5.4	4.9	8.1	7.4
Total	32.5	25.7	65.0	51.2	97.5	76.9

TABLE II

Witness Rods

Test #	Scale	Number of Rods	Rod Length	Tetryl Length	Material
1	0.1	4	30"	26"	Wood
2	0.1	6	30"	26"	Aluminum
3	0.1	4	30"	26"	Aluminum
4	0.2	6	60"	51"	Aluminum
5	0.2	6	60,72"	51"	Aluminum
6	0.3	15	96"	10" Segments	Aluminum
7	0.4	12	96"	10" Segments	Aluminum

TABLE III

Sympathetic Detonation of Acceptors

Test Number	Scale	Distance (in.)	Result
2	0.1	1	-
		1	G
		3	Dummy
		3	G
		6	N
		9	-
3	0.1	2	G
		4	G
		6	G
		8	N
4	0.2	6	G
		8	G
		10	G
		12	G
		14	N
		16	N
5	0.2	9	G
		9	G
		12	G
		12	G
		15	G
		15	G

Test Number	Scale	Distance (in.)	Result		
			Top	Center	Bottom
6	0.3	18	N	G	G
		18	N	G	G
		18	N	G	G
		23	N	G	G
		23	N	G	G
		23	N	G	G
		26	N	N	G
		26	N	G	G
		26	N	G	G
		29	N	G	G
		29	N	N	G
		29	N	N	G
		34	N	N	N
		34	N	N	N
		34	N	N	G
7	0.3	26*	N		N
		26*	N		N
		26**	N	N	N
		26**	N	N	N
		33			N
		33			N
		36			N
		36			N
		40			N
		40			G
		44			N
		44			N

* Confined
**Unconfined
(See Text)

TABLE IV

Crater Dimensions
(feet)

Test #	Scale	c_s	e_s	h_s	c_s (calculated)
1	0.1	10	16		13
2	0.1	12	15		
3	0.1	12	16		
4	0.2	23	34	6.5	24
5	0.2	27.5	38	8.5	
6	0.3	39		13	39
7	0.3	43	55-62	13	

TABLE V

Bulk and Particle Densities at Various Depths in Test 7

Depth in.	ρ_b, (g/cm^3)	ρ_p, (g/cm^3)
10	2.00	2.55
20	1.92	2.36
30	1.96	2.68
40	1.90	2.38
50	1.93	2.74
60	1.87	2.79
70	1.86	2.94
80	2.12	2.96
90	2.08	2.99
98	water level	

TABLE VI

Fireball Dimensions

	0.1 Scale	0.2 Scale	0.3 Scale	1.0 Scale
Fireball Diameter (feet)	19	38	61	200
Fireball Height (feet)	31	79	118	425
Angle of Attack (degrees)	77	74	71	---

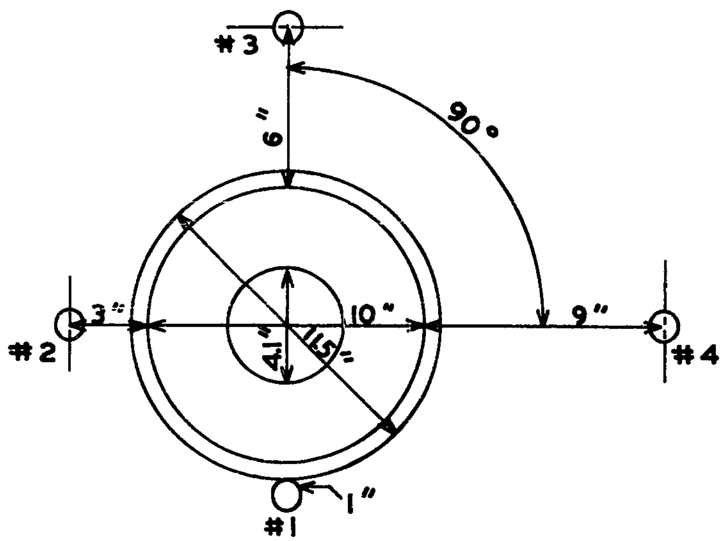
TABLE VII

Scale Based on Charge Diameters

Charge Diameter, in.	Scale	n_s, in.	g_s, in.
4.1	0.095	8	6
8.2	0.191	--	15
10.8	0.251	29	26
12.3	0.286	44	40

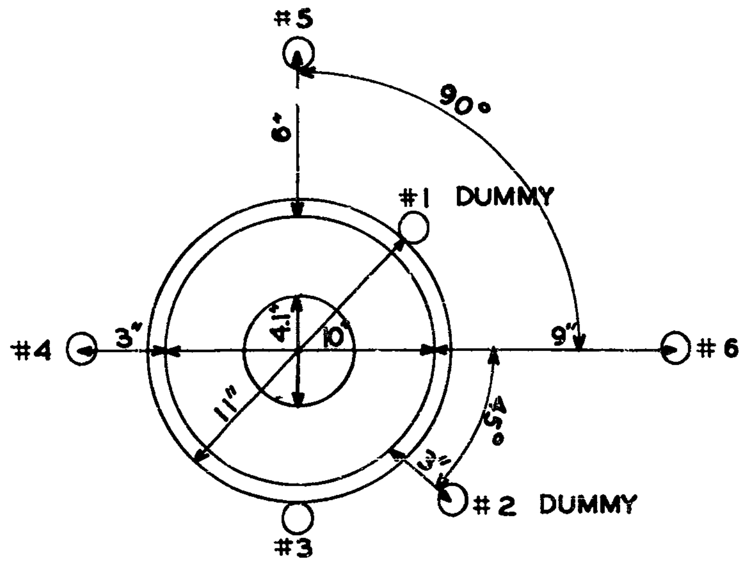
GLOSSARY OF SYMBOLS

a	Shock wave width (time)
c	Crater diameter (feet)
d	Charge diameter (inches)
e	Disturbed earth diameter (feet)
g	Maximum observed "go" distance (inches)
h	Crater depth
k	A constant
n	Minimum observed "no go" distance (inches) ($n_s < g_s$)
p	Pressure
r	Radial distance from charge (inches)
s	Scale factor. When used as subscript it denotes a quantity in scale.
t	Time
E	Total available energy
I	Impulse
I_c	Critical impulse
U	Velocity
W	Mass of charge in pounds
ϵ	Energy scale factor (unitless)
λ	Reduced distance (feet/lbs$^{\frac{1}{3}}$)
π	Pressure scale factor (unitless)
ρ	Density scale factor (unitless)
ρ_p	Particle density of soil (g/cm^3)
ρ_b	Bulk density of soil (g/cm^3)
τ	Time scale factor (unitless)
ϕ	Velocity scale factor (unitless)
ψ	Impulse scale factor (unitless)



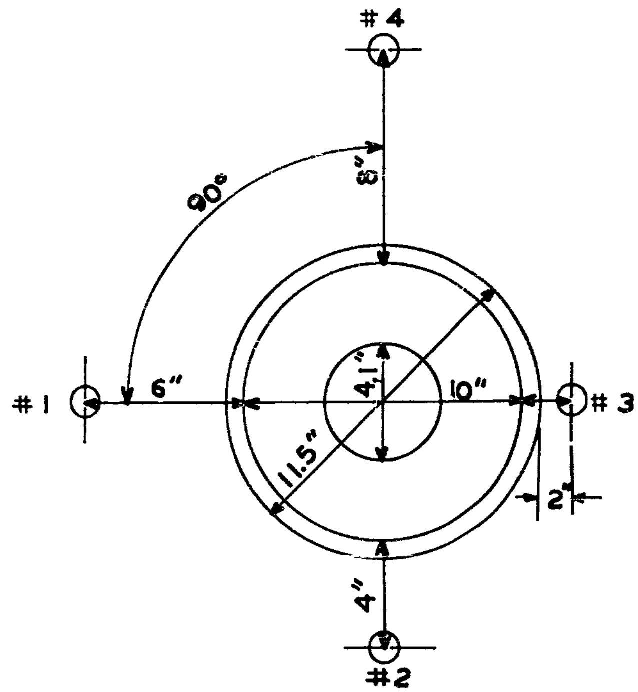
TEST #1

Fig. 1



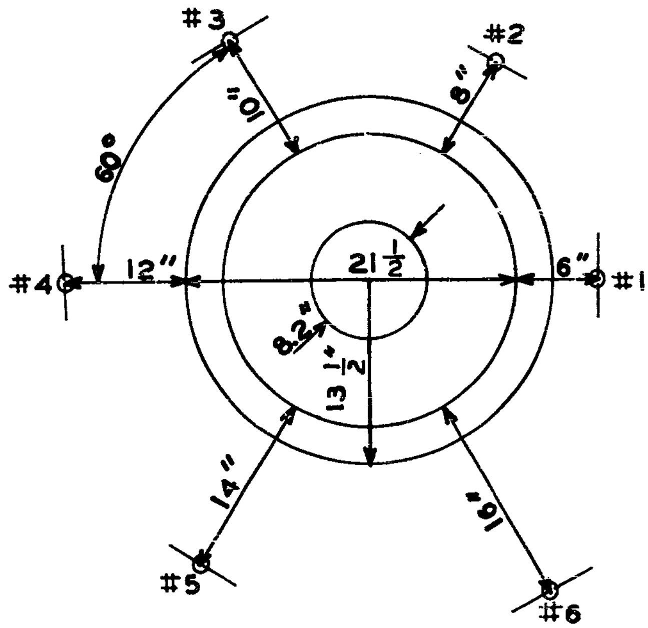
TEST #2

Fig. 2



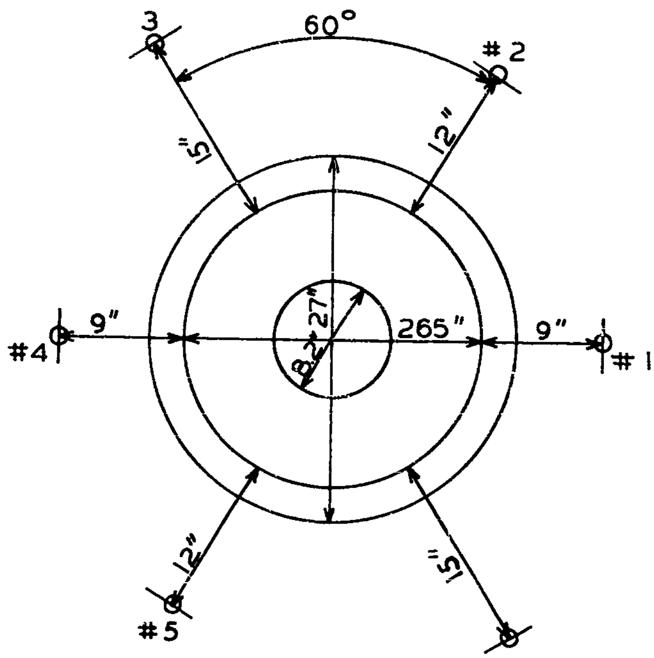
TEST # 3

Fig. 3



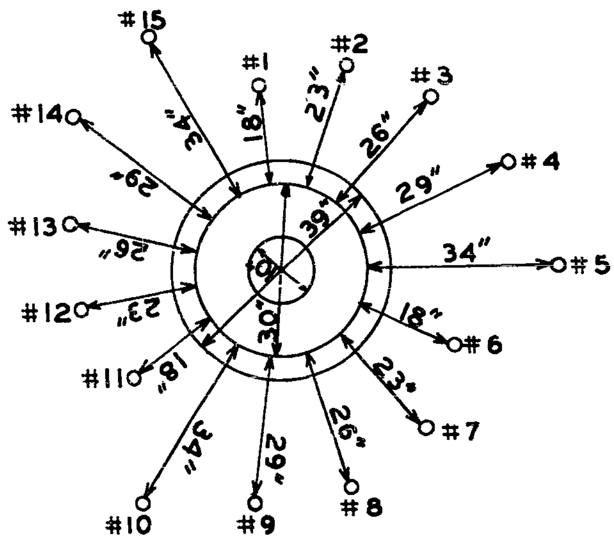
TEST #4

Fig. 4



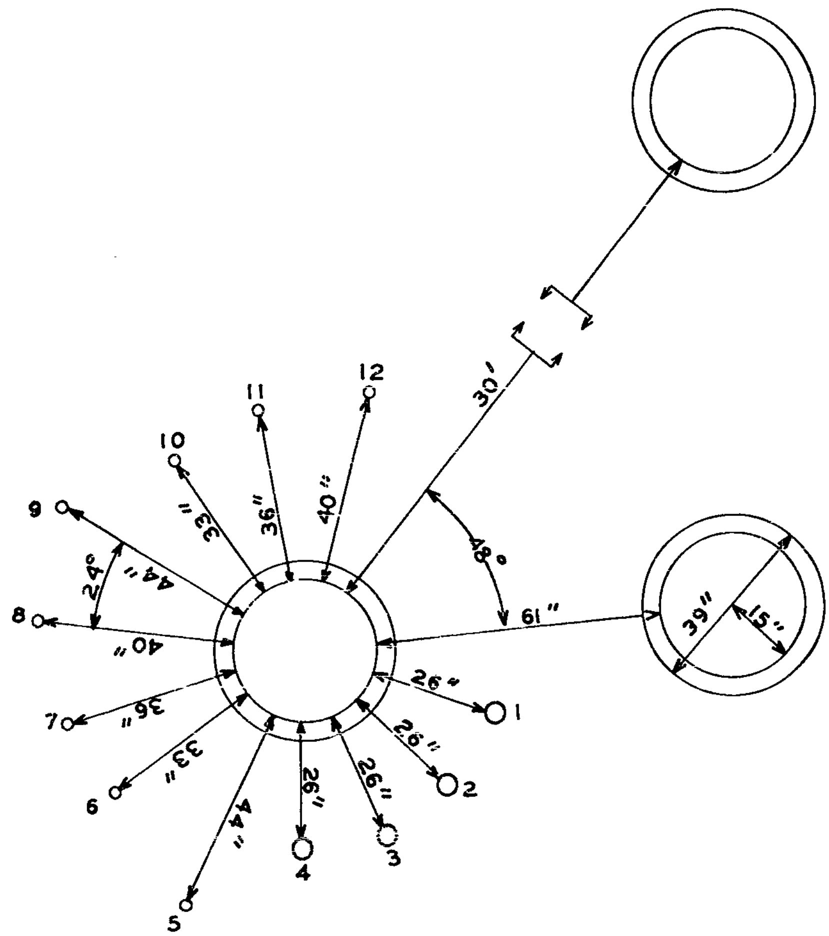
TEST #5

Fig. 5


#15
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
#12
#13
#14
34"
18"
23"
26"
29"
34"
18"
23"
26"
29"
34"
18"
23"
26"
29"
39"
30"
10"

TEST #6

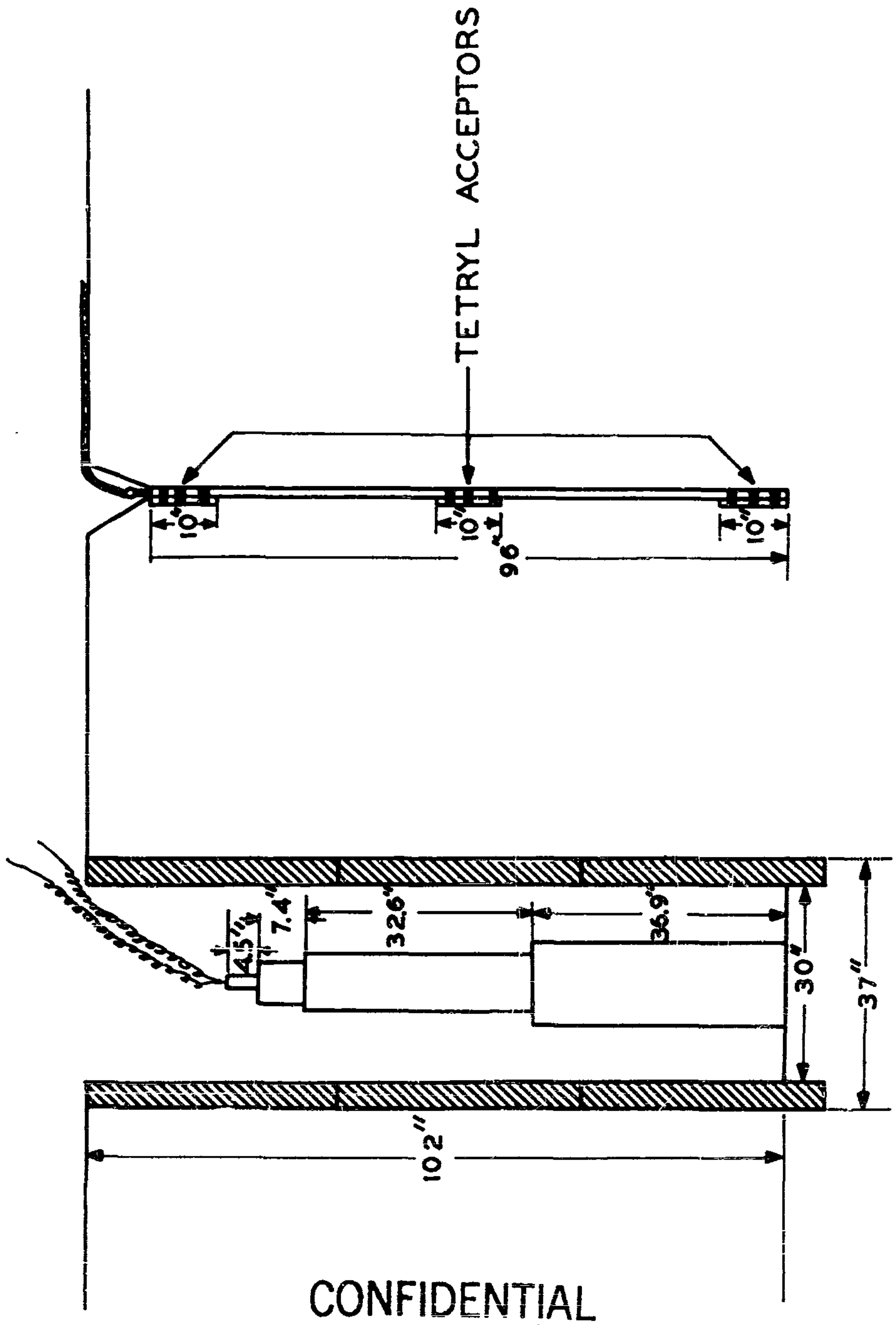
Fig. 6



12
11
10
9
8
7
6
5
4
3
2
1
30'
48°
61"
39"
15"
40"
36"
33"
44"
24°
40"
36"
33"
44"
26"
26"
26"
26"

TEST # 7

Fig. 7



TEST # 6
Fig. 8

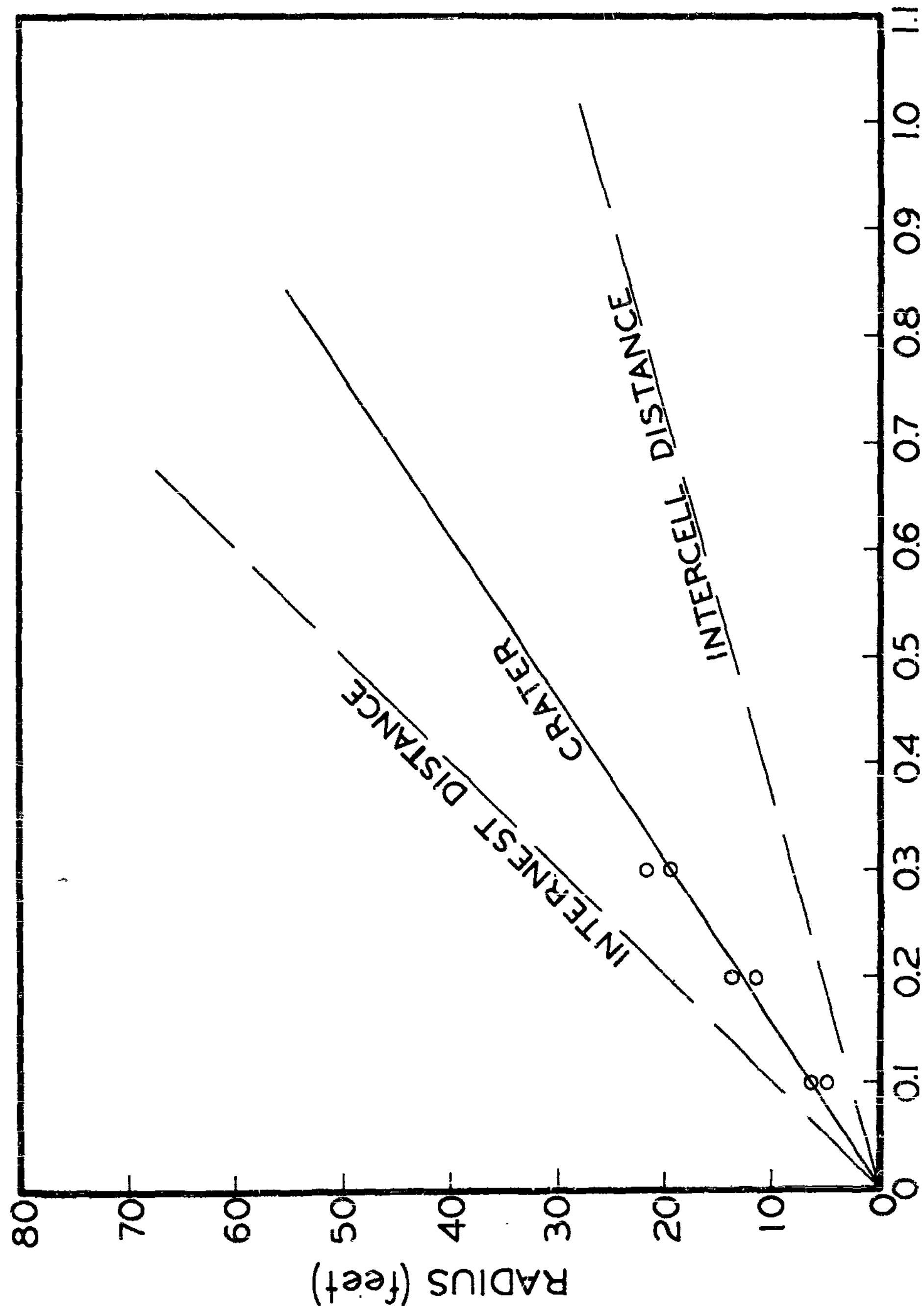

INTERCELL DISTANCE
CRATER
INTERNEST DISTANCE
RADIUS (feet)
0
10
20
30
40
50
60
70
80
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1

Fig. 9

CONFIDENTIAL

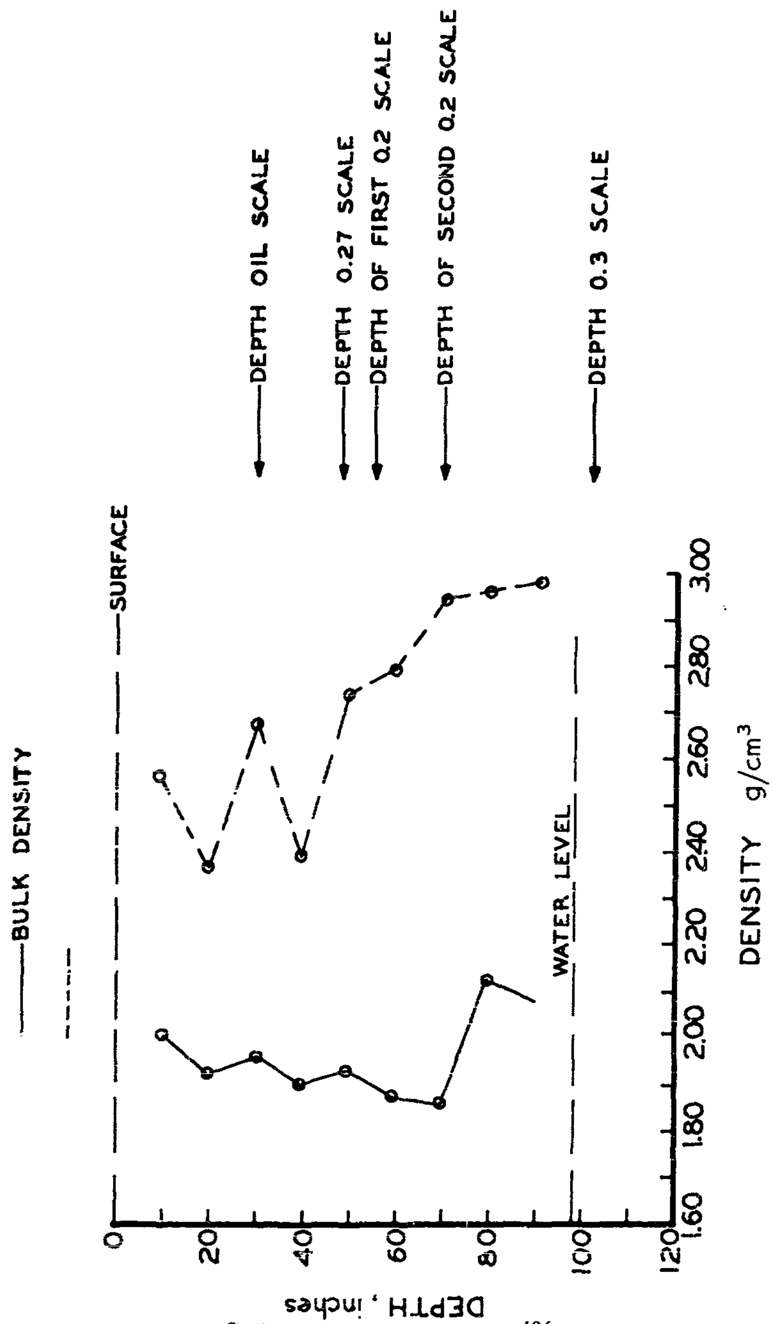


Fig. 10

CONFIDENTIAL

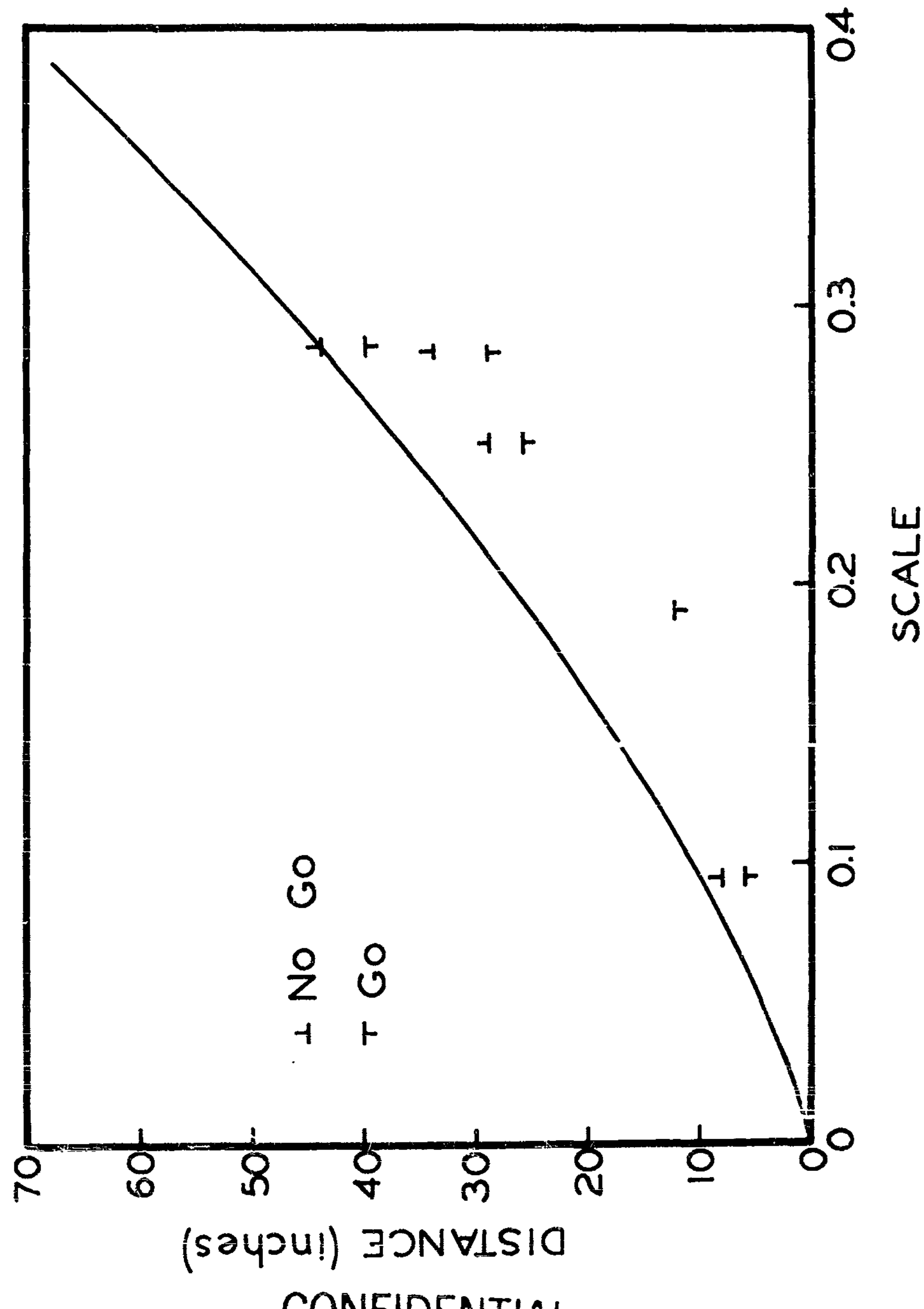


Fig. 11

ENERGETIC ADDITIVES TO PBAA-TYPE PROPELLANT

by
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Introduction:

Polybutadiene copolymerized with acrylic acid, and perhaps also acrylonitrilo, forms the resin basis for a current state-of-the-art propellant binder. The latest work has been with a linear polybutadiene carboxylated terminally(1) which yields generally better physical properties.

These backbones are tied together using trifunctional compounds -- generally epoxides and imines. More desirable physical characteristics are obtained in some instances by use of difunctional extenders and plasticizers.

Generally, these propellants have good low temperature physical properties and can be loaded to high solids contents if pressure-cast techniques are utilized.

Toxicity:

Toxic properties of the polymers are not completely specified; however normal cleanliness practices, to eliminate dermatitis by washing with soap and water, are generally recommended as sufficient. (2)

More hazard is encountered from the crosslinking agents, particularly MAPO(3)(tris (1-2 methyl) aziridinyl phosphine oxide), P-MAPO(3) (phenyl bis (1-2 methyl) aziridinyl phosphine oxide) and other imines, than the PBAA resins. **(Figures 1 and 2)**

Epoxies have dermatitis producing properties which vary with individuals as well as with specific material types. Wide usage has made their properties quite well known generally; therefore, we will only discuss the imines here.

Information on specific physiological properties and tests of MAPO and Phenyl MAPO are contained in an Interchemical Corporation Bulletin ("MAPO" Development Bulletin and "Physiological Properties of MAPO, Phenyl MAPO and MAPS" available from Interchemical Corp., Commercial Development Department, 67 West 44th St., New York 36, N.Y.).

Generally, these imines are hazardous by ingestion and contact but apparently not by inhalation; however, good ventilation is

recommended. Death can occur from very large doses or extensive exposure on the skin; and eye irritation is pronounced (particularly F-MAPO), although absorption into the system from eyes did not occur according to results.

Experience and Formulations:

Another hazard exists in that these compounds will hopolymerize and be violently consumed in reaction and fire when catalyzed with many acid materials. This reaction is observed with ammonium perchlorate and MAPO; however, diluents of practically any sort or very high solids percentage seem to prevent the violent reaction. Tests at 180°F with PETriN, TMETN, and TEGDN yielded varying color changes, generally darkening (reddish as perhaps NO_2 were liberated), and solidification after 24 hours or more; except with PETriN, which did not change after 24 hours (orange color and some slight floc) for 144 hours (end of test).

No problems have been experienced (or noted in literature) in incorporating imine curatives into propellant batches. Care is taken to keep from introducing the curatives onto un-wetted ammonium perchlorate in the mixer. Differential thermal analysis data on various compositions (Tables 1 and 2) are shown in Figures 1 through 3.

It can be seen that by comparison that ammonium perchlorate plays a large part in determining the differential thermogram of PBAA propellants. A basic nitrate ester pattern can then be superimposed on this propellant differential thermogram to evolve the DTA "trace" for nitroplasticized formulae. (Figures 3,4,5,6)

Tables 3 and 4 show information available to date on various of these propellants and Table 5 gives some comparisons with several types of propellant and single ingredients. The 50% point impact sensitivities run on a Bureau of Mines apparatus with flat anvils and 2 kg-weight are essentially unchanged from B-13 and X-24 in C-102, C-103, C-104, C-105, D-100, and E-102 which are nitroplasticized at a 4% level. CY-12 is less sensitive, as expected, due to $AgIO_3$ "oxidizer" and no ammonium perchlorate. The data on C-106 are based on audible noise -- smoke emission occurred at lower values but no visible sample change could be detected.

None of the card gap tests[4] were propagative except for the C-106, which is 50% HMX, at zero gap (no cards).

It can be seen that the nitrate esters are quite sensitive ingredients (Table 5). In fact, they are generally more sensitive if extremely pure. Shipment and general handling are done in a desensitized condition (diluent solvent), but usage requires removal of the de-sensitizing agent. It is worth recognition that applied propellant researchers are well on their way toward making obsolete most low energy (hence non-sensitive) propellant ingredients. More

oxidizer is being chemically "buil   ers and fuels, as well as fuel into the oxidizers, which necessarily makes handling difficult.

However, relatively good accident records throughout the propellants and explosives industry prove that knowledge of the hazards and common sense precaution, along with remote operations where possible, make usage of these materials feasible.

Future Areas of Endeavor:

NF_2 additives, rather than nitroplasticizers used, and nitrated or fluorinated reactants to form the basic resins are possible future areas of interest for PBAA type propellants.

Beryllium is another current fuel topic and will be utilized in these propellants and others at the U. S. Naval Ordnance Test Station. Some work has been done at Atlantic Research Corporation and elsewhere on polyurethanes, PBAA's, and other systems. Hazards here are of the inhalation type predominantly and will concern firing areas mainly, since processing handling will be protected by special ventilation and use larger (non-inhalable) material. Except for accidents such as explosion or fire which would create hazards similar to firing.

Another area which may claim attention of propellant makers is incorporation of higher energy (hence more dangerous) oxidizers such as nitronium perchlorate, TAG azide, HMX, etc.

Further testing is anticipated and in progress on several of the propellants in this report, particularly Butarez CTL II with imine cure, nitroplasticizers, and silver iodate since usage of this material is anticipated in an extensive test program.

The composite propellant development group at the U. S. Naval Ordnance Test Station generates a complete set of pilot data on promising formulations and reports these data as a "characterization".(5)

(1) BUTAREZ CTL - Phillips Petroleum Co. and HC-434 - Thiokol Chemical Co.
(2) HC 434 Liquid Polymer Bulletin 2C-4/62, Thiokol Chemical Corp., Trenton, N. J.
(3) Interchemical Corp., N. Y. 36, N. Y.
(4) NAVORD Report 5788 details method which involves two 2" diameter x 1" tetryl pellets, a #8 blasting cap, and a 1-1/2" steel pipe 5-7/16" long full of the sample.
(5) (a) NOTS IDP 1086, Preliminary Report on the Characterization of Nitrasol V2818 Propellant.
    (b) NAVWEPS Report 7643, Characterization of C-509 Propellant.
    (c) NAVWEPS Report 7891, Characteristics of N-23 Propellant.
    (d) NOTS IDP Memo Reg. No. 4571-60, Characterization of X-24 Propellant.

TABLE 1

FORMULATIONS

	B-13	C-3	Mod C-3	CY-6	CY-12	P-65
AP (G & B)	64.000	69.00	67.65			
Al-1230	18.000					
PBAA TER	15.849					
MAPO	.683	.294	.288	.327	.170	
P-MAPO	.468					
Fe_2O_3	1.000					
Al-123		17.00	16.67		1.500	5.00
Butarez CTL II		13.706	13.44	11.173	5.830	
Liquid PB			1.96			
$AgIO_3$				85.00	90.000	65.00
TMETN				3.50	2.500	
PNC NPPK						8.50
PETriN						21.00
Resorcinol						0.50

TABLE 2

FORMULATIONS

	B-104	B-102	C-102	C-103	C-104	C-105	D-100	E-102
A1-1230	18.00	18.00						
AP	63.30	63.80						
PBAA TER	12.119	11.63						
MgO	.06	.06						
ZnO	.14	.14						
TEGN	5.00			4.00		4.00	4.00	
MAPO	.514		.298	.298	.256	.256	.266	.446
P-MAPO	.367							
ERL 3794		1.37						
TMETN		5.00	4.00		4.00			4.00
AP (G&B)			69.00	69.00	69.00	69.00	69.00	69.00
A1-123			17.00	17.00	17.00	17.00	17.00	17.00
BUTAREZ CTL II			9.702	9.702	9.744	9.744		
PBAA 445							9.734	
HC 434								9.554

TABLE 3

SENSITIVITY DATA

	B-13	C-3	Mod C-3	CY-6	CY-12	P-65	C-106
Impact, cm (2 kg wt)	22.8				33.7	16	(50.5)
Electrostatic	10 no				10 no	10 no	10 no
Friction	10 no				10 no	10 no	10 no
DTA (initial exotherm) (heating rate)	366°F	255°C 5°C/min	255°C 5°C/min	150°C 4.83°C/min	(75°C) (4.84°C/) (min)	180°C	210°C 5.75°C /min
Gap Detonation	6 no at zero gap				3 no at zero gap		3 yes at zero gap
Cook off (hours) (temp.) (size)	11.5 344°F 5" dia. x 6"					2.4 245°F 1" dia. x 1"	
Autoignition (5°F/min/gram)	438°F						
H_{ex}(cal/gram)	1385	1507	1426	354	497	907	

TABLE 4

SENSITIVITY DATA

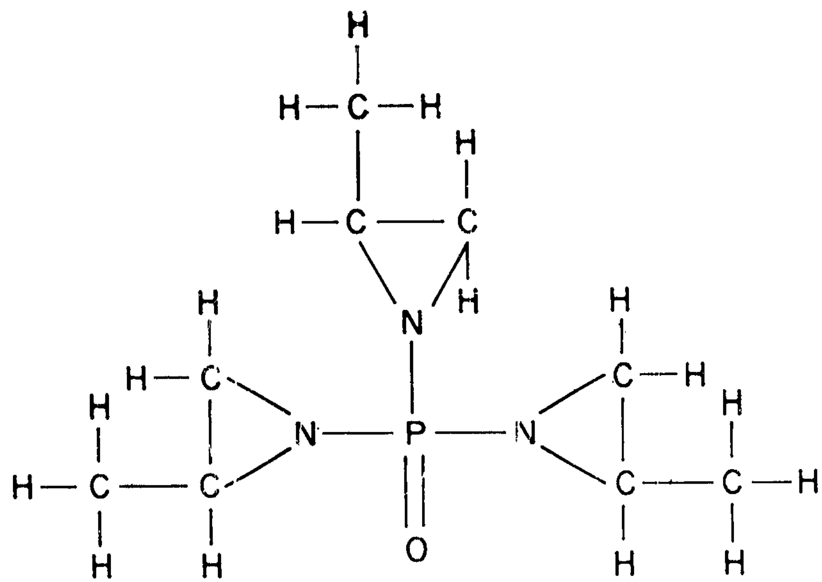
	C-102	C-103	C-104	C-105	D-100	E-102	X-24
Impact, cm (2 kg wt)	20.0	20.0	18	15.5	25.5	15.5	25.3
Electrostatic	10 no	10 no	10 no	10 no	10 no	10 no	10 no
Friction (kg-cm)	10 no	10 no	400.4	10 no	(404.8)	10 no	10 no
DTA (initial exotherm) (heating rate)	165°C 4.84°C/min	260°C 4.8°C/min	185°C 5.76°C/min		255°C 4.8°C/min	260°C 4.8°C/min	299°F 5.05°F/min
Gap Detonation			3 no at zero gap	3 no at zero gap			6 no at zero gap
Cook Off (hours) (temp.) (size)							26.1 365°F 5" dia. x 6"
Autoignition (5°F/min/gram)							588°F
H_{ex}(cal/gram)	1715	1697	1718	1693	1696		1138

TABLE 5

SENSITIVITY COMPARISON

	Card Gap (in.) Plastic Method	Wax Disc. (Cast)	Heat of Explosion (Cal/gm)	Impact (Kg-cm)	Friction Steel Shoe (Kg-cm)	Cook Off
Standard X-12	.367					
Comp. B	2.032	1.40	1240	150	Unaffected	212°F-100 hrs. No Exp.
NG			1600	30	Explodes	" "
Baratol		.32		70		
NH_4ClO_4				134	Snaps	212°F-100 hrs. No Exp.
PNC			956	164	Snaps	
TMETN	.125			94.8	Explodes	212°F-100 hrs. No Exp.
PETriN	.459		1204	25		
TEGN			357	200	Unaffected	212°F-100 hrs. No Exp.
E-107	.000		1149	42.8		311°F-7 days detonated
Cured H-3515	1.004		1776	17.6	Snaps	212°F-16 hrs. Cook-off
Uncured H-3515	1.480					
Porous	1.745					
Black Powder			684	64	Snaps	
B-13	0-6 no		1385	45	Unaffected	344°F-11.5 hrs.
X-24 (BFG C-505)	0-6 no		1138	50	"	365°F-26.1 hrs.
CY-12	0-3 no		497	67	"	
C-105	0-3 no		1693	31	"	
RDS 507				45		620°F-5 min.

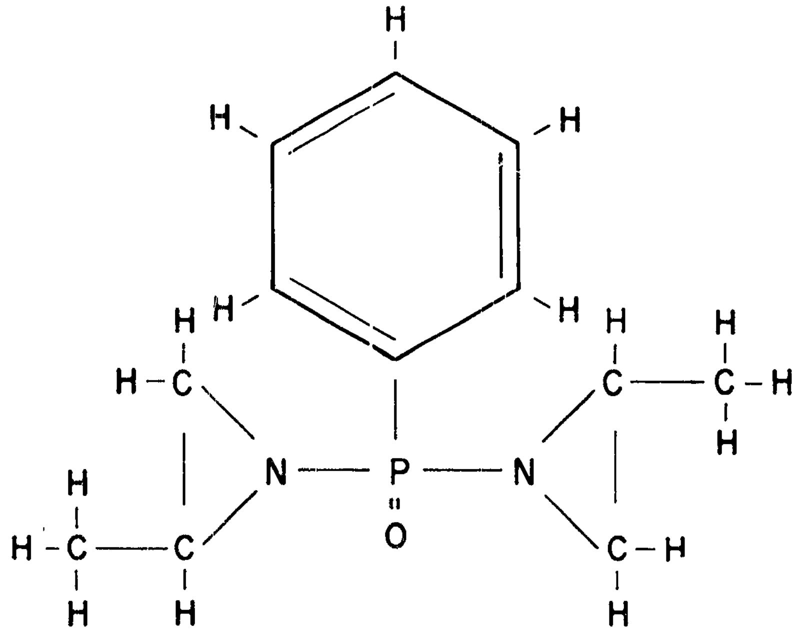
MAPO



(TRIS [1-(2-METHYL) AZIRIDINYL] PHOSPHINE OXIDE)

Figure 1

P-MAPO



(PHENYL BIS [1-(2-METHYL) AZIRIDINYL] PHOSPHINE OXIDE

Figure 2

DTA THERMOGRAMS

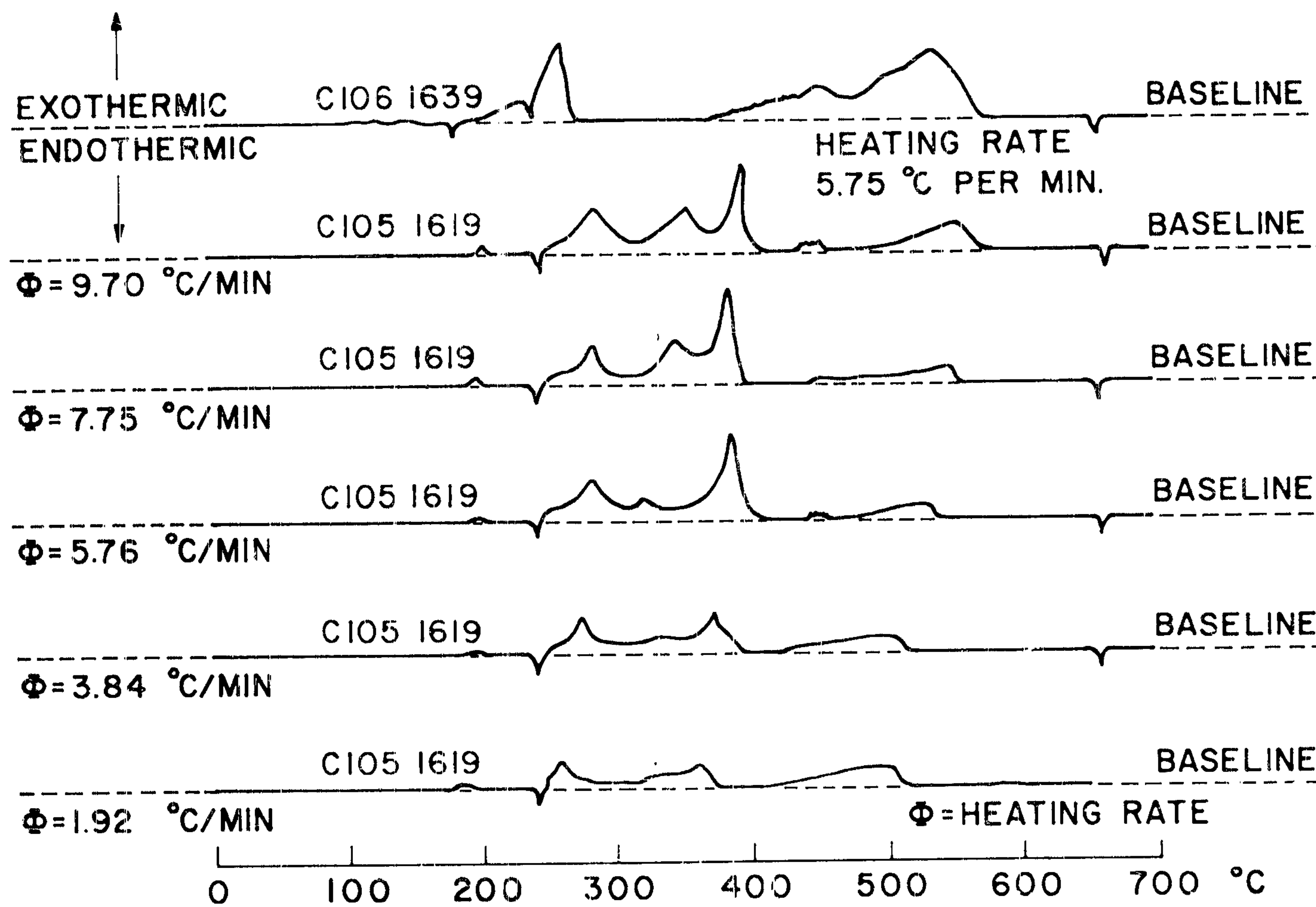


Figure 3

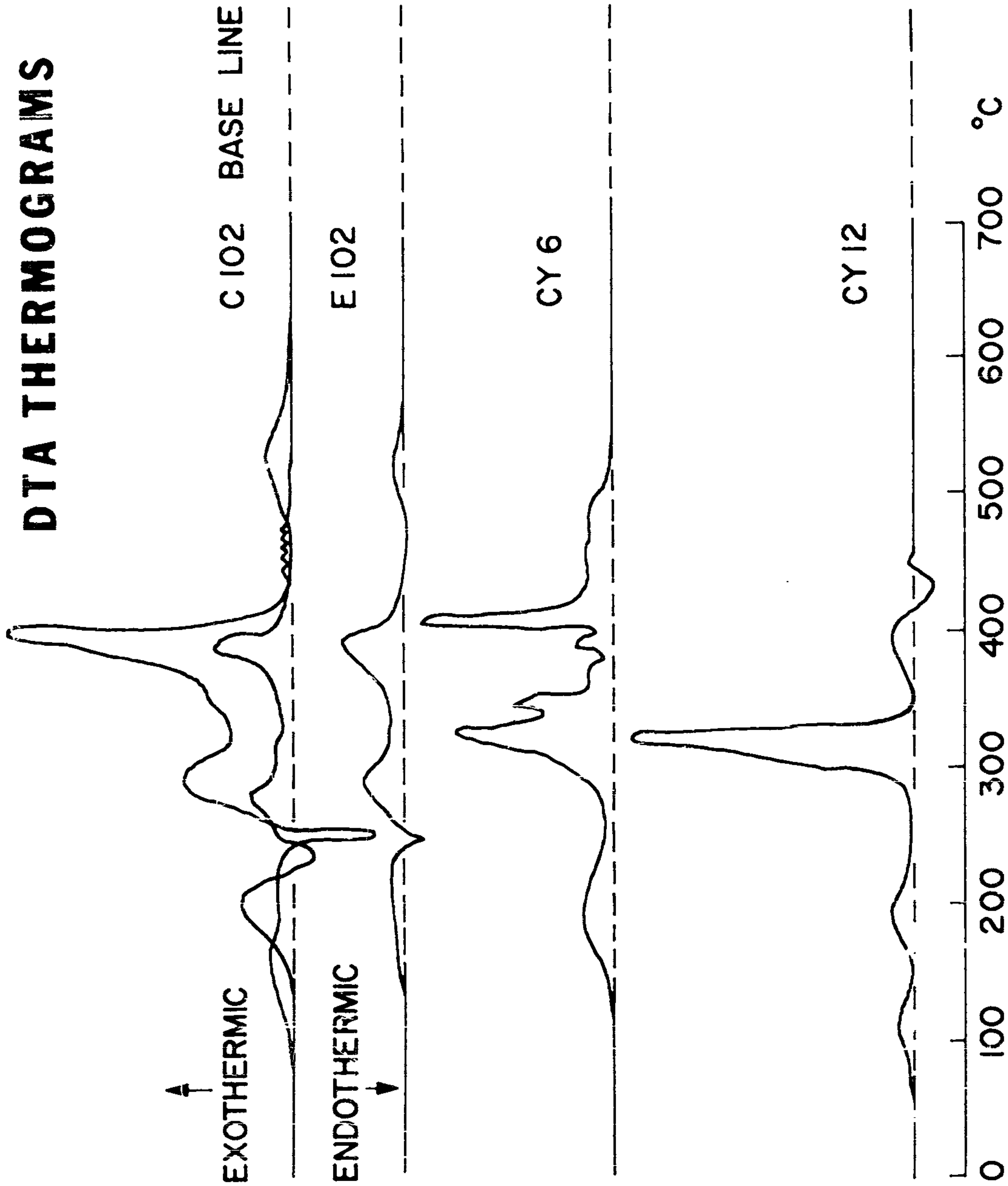

DTA THERMOGRAMS
BASE LINE
C 102
E 102
CY 6
CY 12
EXOTHERMIC
ENDOTHERMIC
0
100
200
300
400
500
600
700
°C

Figure 4

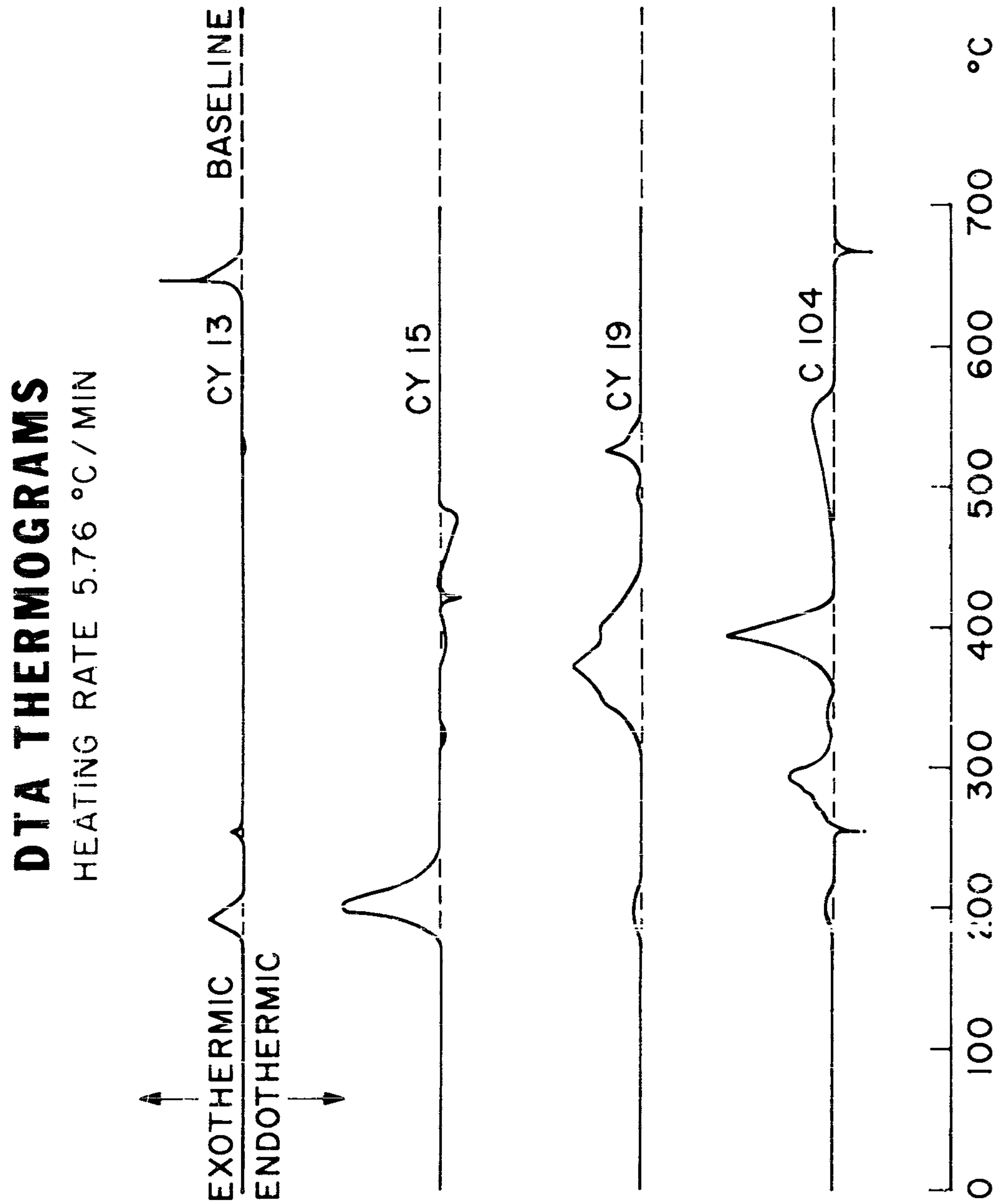

DTA THERMOGRAMS
HEATING RATE 5.76 °C / MIN
EXOTHERMIC
ENDOTHERMIC
BASELINE
CY 13
CY 15
CY 19
C 104
0
100
200
300
400
500
600
700
°C

Figure 5

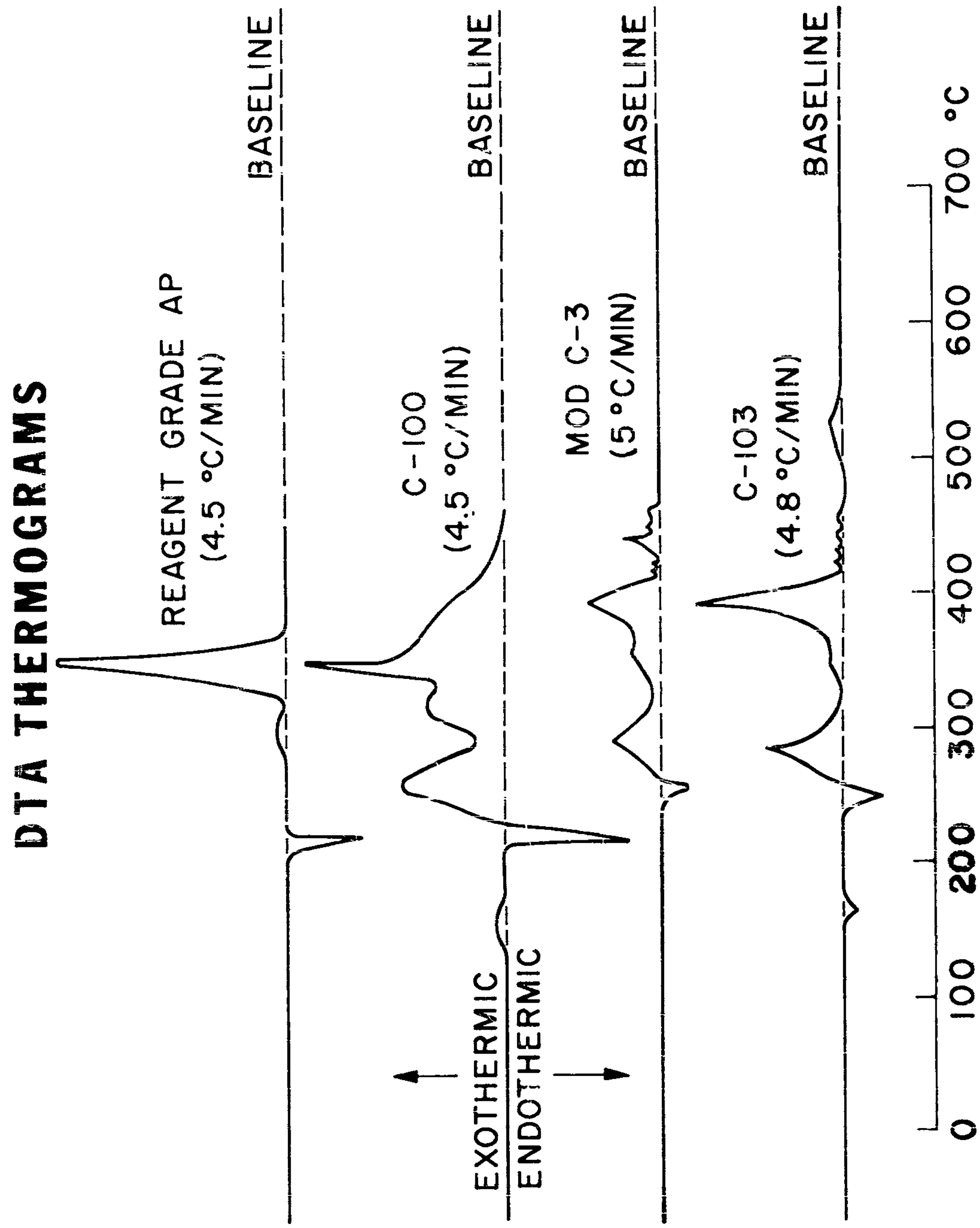

DTA THERMOGRAMS
REAGENT GRADE AP
(4.5 °C/MIN)
C-100
(4.5 °C/MIN)
MOD C-3
(5 °C/MIN)
C-103
(4.8 °C/MIN)
BASELINE
BASELINE
BASELINE
BASELINE
EXOTHERMIC
ENDOTHERMIC
0
100
200
300
400
500
600
700 °C

Figure 6

REVIEW OF NAVAL ORDNANCE TEST STATION BERYLLIUM PROPELLANT WORK AND FUTURE PLANS

by
Dr. G. Rice
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Among the important new safety problems in the propellants industry is the proposed use of beryllium as a fuel in large upper stages of deterrent missiles. What is the reason for the use of beryllium in propellants? A fundamental approximation for estimating performance of a propellant is the relation that specific impulse is proportional to the square root of the heat released per gram of fuel and oxidizer. The specific impulse is further inversely proportional to the square root of the average molecular weight of the products. Inspection of the periodic chart shows that Be, Li, B, Al and Mg have the greatest promise as metallic fuel additives based on this simplification of the Isp criterion. Lithium's low melting point and density and extreme reactivity have of course worked against it. Boron has shown low combustion efficiency in most investigations so far. Aluminum has proven superior to magnesium, and the use of aluminum is now standard practice in high energy solid propellants.

Small motor firings indicate that an increase of 12-16 Isp units is possible by substitution of beryllium for aluminum with necessary adjustments of oxidizer/fuel ratio (1,2). A major point is that beryllium with conventional inert binders and oxidizers gives impulse greater than aluminum systems containing high energy binders and oxidizers -- such materials as nitrocellulose, TMETN, HMX, and RDX. In other words we would be balancing the risk of accidental release of toxic compounds by a greatly reduced risk of accidental initiation.

Pursuing performance calculations a bit further, the burnout velocity, velocity of a rocket when the propellant is all consumed, is another important parameter, since the range of a missile is approximately proportional to the square of the burnt velocity. Exact calculation of the burnt velocity of course involves weight of motor case, weight of payload, weight and specific impulse of the propellant. However, in the case of a first stage, where the propellant and hardware for upper stages constitutes a payload as it were, the ratio of the mass of payload and hardware to volume of propellant is large and propellant density becomes important. For example, above mass to-volume ratios of 50 lbs/cu ft, zirconium-containing propellants are superior in performance to beryllium-containing formulations. Beryllium has a density of 1.85 g/cc compared to 1.7 for magnesium, 2.7 for aluminum, and 6.5 for zirconium. Thus beryllium would not appear useful in first

stage applications, but would instead be used for space and upper stage propulsion. Use of beryllium propellant with conventional inert binder and ammonium perchlorate for the second stage of Polaris for example can give a calculated increase in range of up to 10% above that for high energy aluminum propellant containing detonable or thermally unstable nitrate esters, nitramines, or nitrocompounds (3). Toxic products from a second stage would of course be diluted to extremely low concentrations before reaching the ground, but crews and the general public in the neighborhood of launch sites should be protected from the toxic products arising from an accident in which an upper stage is ignited. Offhand it would seem more practical to use beryllium-containing propellant in missiles deployed at sea rather than at ground sites.

There are other causes besides toxicity for the seeming delay in the exploitation of beryllium in propellants. These have included questions as to the cost and strategic availability of the material in the ton quantities necessary for any large motor applications (3-6). The hazard and gains to be derived from the use of beryllium in propellants are being evaluated by several responsible groups (4). Aerojet and Atlantic Research Corp. have been actively working with beryllium for the past two or three years on contracts with ARPA, the Navy, and the Air Force. Hercules, Thiokol, Rocketdyne, and Rocket Power have begun work with beryllium propellant since January of this year. NOL Corona, Esso, and Metal Hydrides have been engaged in synthetic programs with beryllium compounds. Dow has an active biochemical research group studying toxicity of beryllium compounds and of rocket exhaust products. Aeronutronics is studying combustion of beryllium metal particles and beryllium alloys. There is no doubt that other groups are engaged in some non-contracted work, and that as favorable experience increases, more and more companies will recognize that adequate hygienic controls are possible and will enter active work. The propellant industry realizes that the hazard is greater in some respects than the hazards encountered heretofore with beryllium and that one case of berylliosis in the industry would be a serious detriment to the utilization of beryllium propellants in any missile system. It is often difficult to reinstitute a program which has been halted because of an accident, even after causes of the accident have been found and corrected.

There is an extensive literature on the toxicology of beryllium (7-16). Among the topics about which there is no clear-cut opinion or there are differences of opinion are, for example, susceptibility differences between the sexes and for different age groups, the relative toxicities of soluble and insoluble compounds, the question as to whether or not reaction to beryllium is an allergy response, and so on. The following is a simple picture of the toxicity problem in which controversies are avoided. Absorption from the gastrointestinal tract is poor and therfore oral ingestion is not considered a danger -- eating and smoking in work clothing is not prohibited at some installations. Skin reactions are of two types: a dermatitis resulting from contact

with salts and non-healing ulcers from particles implanted either through open wounds or by penetrating injury. These are not serious but of course provisions are taken to prevent such contacts. The beryllium toxicity of greatest seriousness is that due to respirable forms of beryllium. First there is an acute pneumonitis developing soon after exposure to high concentrations with symptoms including chills, fever, cough, and fluid accumulation in the lungs. Recovery from non-fatal cases, with proper medical care, may be complete. Second, there is chronic berylliosis, which may develop several years after exposure. The characteristic feature is a decrease in functional capacity of the lungs. This severely limits the energy of the victim and in some cases may completely immobilize him. Medical treatment is of only limited effectiveness and the condition persists for life, which may be markedly shortened due to the increased burden on the heart.

The allowable atmospheric concentrations generally accepted are those recommended by the AEC (7). For the worker, a safe lifetime industrial exposure is considered to be 2 micrograms/m^3 averaged over an 8-hour working day. For the neighborhood, a level of 0.01 micrograms/m^3 averaged over a 30-day period is the limit. If the in-plant concentration exceeds 5 micrograms/m^3 or the neighborhood concentration exceeds 0.05, operations will be halted. These limits appears straightforward. However, the 25 micrograms/m^3 as the maximum allowable concentration for a single air sample for any period of time however short, is subject to varied interpretations. This is due to omission of specified sampling periods and rates and further, the impossibility of instantaneous sampling. A high short-duration concentration can be diluted by drawing relatively uncontaminated air through the sampler before and after the peak. An arbitrary decision as to sampling times and rates appears necessary for each beryllium user and for each specific operation. The American Conference of Governmental Industrial Hygienists (17), the American Industrial Hygiene Association (18), and the United Kingdom Atomic establishments have dopted the AEC levels at least tentatively and have further recommended a 20 or 30 minute sampling period with high volume samplers for assessing the peak concentrations. A maximum allowable peak concentration of 25 micrograms/m^3 in a sampling period of 20 minutes has led to the utilization by some beryllium users of a total integrated dose of 500 microgram-minutes/m^3 as the maximum allowable short term exposure. Thus a concentration of 500 micrograms/m^3 can be tolerated for one minute, 1000 micrograms/m^3 for 30 seconds, and so on. Some authoritative interpretation of this total integrated dose concept is necessary for the propellant industry because planned releases, as in static firing, will result in short term high level concentrations. Also the total integrated dose concept would appear to have greater physiological validity than concentration.

There is some evidence that the AEC levels are more conservative than necessary (7). The limits are such that new cases of disease are exceedingly rare. Few concentration data are available for periods when

concentrations were high enough to have produced disease, and now no data on disease are forthcoming when concentration data are abundant.

We believe that NOTS China Lake can produce large motors containing beryllium for testing its use in upper stage missile applications. The Propulsion Development Department has a 150-gallon vertical mixer and a thrust stand for static testing of large motors. More important than the facilities themselves however, is the local meteorology and the location of the facilities with respect to adjacent populated areas. There will always be a calculated risk as to whether or not sufficient distance to unprotected neighbors is available to allow dispersion of a toxic cloud under the most unfavorable meteorological conditions. Planned releases can of course be scheduled for periods of favorable meteorological conditions and the more potentially hazardous operations can also be restricted to periods of favorable conditions. In addition, in order to reduce risk periods, the motor should be stored a minimum of time following cure.

The NOTS China Lake area is a desert region having wide sweeps of terrain over which meteorological conditions are constant and predictable. Useful micrometeorological data for such areas have been compiled at the National Reactor Test Station at Arco, Idaho and at the Army Chemical Corps Proving Ground at Dugway, Utah. Complete records of weather at NOTS are available for the past sixteen years (19-21).

For any particular wind pattern, dispersion and dilution of a toxic cloud would be dependent on the turbulence of the air, which is a function of ground temperature and air temperature of the lower layers. During the daily period of high temperature, the temperature gradient is lapse or unstable, and vertical dispersion or mixing of the air layers is most favorable. For the months of April thru September 40-70% of the winds during the daily lapse (noon to 8 pm) are from the southwest quarter and average more than 11 knots. Such strong wind would be constant and such conditions are ideal for our purpose. The nearest populated area from the mix station is six miles due west, requiring an uncommon east wind. The nearest downwind populated area is eleven miles east-northeast. The test stand is seven miles from the nearest downwind populated area. The test stand and the mix station are both much closer to other work areas, but these can be evacuated during all actual operations with beryllium on this large scale.

Preliminary calculations based on diffusion theory as developed by Sutton (22, 23) indicate that the conditions above would provide a sufficient margin of safety to mix, cast, and fire motors as large as 7500 pounds (3). It will be necessary that the program be closely coordinated with meteorological, industrial hygiene, and safety groups throughout the planning stages.

The safety controls and checks under which we are working are quite stringent. In the first place, beryllium is a "controlled" material on

the base, which means that purchase, storage, and use must be arranged and reviewed through the base Safety Officer. This officer has the assistance of the Medical Officer and the Industrial Hygienist in assuring that the plans submitted for storage and use of the material will provide sufficient protection against the potential hazard. There is also a Toxic Materials Advisory Committee with the Medical Officer or the Industrial Hygienist as Chairman and the Safety Officer and technical personnel of wide background among the members. It serves in advisory capacity, but there are mechanisms to insure adoption of their recommendations. In addition the Propulsion Development Dept. has its own safety group, a Supervisors Safety Committee and a New Materials and Processes Committee made up of technical personnel, again acting in an advisory capacity. Finally at the working level there is a special Beryllium Committee within the Department which serves to coordinate and review plans before they are submitted up this somewhat lengthy and branched chain of check and counter check. The number of responsible people thinking and assisting in the control of beryllium on Station will far exceed those actually working with it.

The Medical Officer has set up rigid physical requirements for screening personnel who will be permitted to work with beryllium. Thus far, approximately one third of those examined have failed the criteria:

1. Persons with skin disease.

2. Persons with a history of asthma or repeated respiratory infections.

3. Persons with significant past exposure to industrial dusts, silica, etc.

4. Persons with organic heart disease.

5. Persons with a history of tuberculosis.

These criteria were set on the basis that such persons have a greater than average likelihood of developing beryllium disease or have cardio-pulmonary conditions that may be confused with the changes seen in chronic beryllium disease.

Our immediate plans call for small scale work at mobile facilities located in the general area of the test stand. This is called Operation BOONDOCK. It consists of equipment for the preparation of 2" diameter extruded grains and of cast grains of 2, 5, and 12" diameter. An air-conditioned van has been equipped for remote control of many of the operations and will be located 100-300 yards upwind of the mixing and extrusion site. In addition to the air-conditioned van, personnel protection includes masks with ultra filters, air supplied masks, air packs, protective clothing, and clothing change and shower facilities.

Beryllium powder for the extruded propellant has been ordered in pre-weighed units and will be shipped wet with the liquid used in the shock gel process. Beryllium powder for the cast propellant will be opened and weighed in a glove box equipped with ultra filters and will be wet with liquid binder ingredient before removal from the glove box.

A van with meteorological instruments and personnel will be available during working periods. Operations will be conducted only under suitable meteorological conditions and sampling and decontamination procedures will be thorough. Three types of air samplers are available: (1) portable high volume samplers which operate on 110 volt AC and give a sampling rate of 18 cubic feet per minute through 4" disks of Whatman #41 filter paper. These will be running during processing and will also serve to spot check areas of possible contamination; (2) individual breathing zone samplers. These are battery operated and will be clipped onto the suits of the workers; (3) rugged fixed site high volume samplers for continuous monitoring. Analyses are performed by arc spectrograph.

The extrusion facility at BOONDOCK is mounted on a flat-bed four-wheel trailer. The extruded grains to be manufactured are a fluorocarbon formulation with which there has been wide experience with aluminum and zirconium. Air compressors drive the stirrer for the slurry kettle in which the binder is shock-gelled from solution onto the metal and oxidizer. The liquid is then decanted and the molding powder then transferred to an oven for drying and preheating. The oven, the 3" press, its hydraulic pump and reservoir, an oil heating and circulating unit to furnish heat for the die, and a vacuum pump for evacuation of powder in the extrusion chamber are all mounted on the trailer. Recorders, gauges, and valves for the remote control of the press and remote monitoring of hydraulic oil pressure, extrusion-chamber pressure, and temperature of heating oil in and out of the die are mounted in the air-conditioned van. The two men mixing the propellant, extruding the 2" grains and assembling the motors are capable chemical engineers. It is realized that scale-up in motor size usually yields an increase in performance and that our plan here is limited to 2" motors, but there are at present no data at all on the combustion efficiency of beryllium in fluorocarbon binders and BOONDOCK offers a simple and safe way to prepare motors. Cast fluorocarbon binders may be utilized later and larger motors for scale-up data will then be feasible.

The BOONDOCK cast facility consists of a trailer van fitted with 1-pint, 1-gallon and 5-gallon vertical mixers and accessory equipment. The mix station is separated from the utilities by a barrier wall. Mixing of propellant will be done remotely from the control van. It is planned that an inert state-of-the-art propellant binder to be utilized for the large motor program be studied first. As BOONDOCK proceeds, a room in the regular processing area is being fitted with ultra filters and entrances through an air lock. Here can be safely conducted the strand-burning, heat of explosion, mechanical properties

testing, and safety tests on beryllium propellant necessary for final choice of the formulation to be used for the large motors. These or other procedures will also be utilized for in-process quality control for mixing of the large motors.

A portable firing stand and instrumentation are ready for firing of 2 and 5" motors. These can be used at either San Nicholas Island which is Navy-controlled, a meteorologically favorable location at China Lake or at a containment facility being constructed on the base. The latter is a remote abandoned mine shaft into which exhaust gases will be led and cooled and trapped with water spray. Exhaust to the atmosphere will be through a scrubbing and ultra filter system.

For the preparation and firing of 2" motors such as will be made by extrusion at BOONDOCK, there are required no safety tests, burning rates, heat of explosion, mechanical properties studies, or chemical analyses. Formulations will be chosen on the basis of theoretical calculations and known behavior of analogous aluminum or zirconium compositions. Sensitivity of beryllium propellants should be similar to that of the same formulations with other metals, but the worst will be assumed sensitivity-wise. Burning rates can be extrapolated from data on aluminum propellants with sufficient accuracy to allow an initial firing. This first firing will provide the necessary data for determination of proper nozzle port area to achieve the standard chamber pressure of 1000 psi on further firings.

Summarizing, at BOONDOCK we will be operating with relatively small amounts of propellant, in a remote area and with a small number of people. The procedures and equipment will be familiar and there will be a few high risk operations. Thus we will not be working with only a narrow margin of safety. BOONDOCK can thus proceed while the very necessary micro-meteorological studies are being made for the 150-gal. mix station and the large motor test stand. BOONDOCK in the meantime is giving us valuable training and experience with local meteorological conditions, monitoring equipment and procedures, and providing useful data on specific propellant formulations.

Mr. Couch: Is the State of California aware of your work in this?

Dr. Rice: The State of California has been aware of work in this area and we have not contacted them as yet. We know of people who have.

Mr. Couch: Do you know what their reaction is?

Dr. Rice: The reaction has been quite agreeable in working with people in this area. I think if there is an attempt at concealment or secrecy, this is bad. I think the work should be done openly with knowledge of the people. That's one of the reasons why I wanted to make a presentation here - it's in the open.

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ACCOUSTICAL EFFECTS OF LARGE ROCKET MOTORS

by
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Inasmuch as this is the last presentation for this seminar, I will attempt to be very brief and factual relating this discussion toward the safety aspects, which will eventually be a prime task for this group, rather than a detailed technical report on the theory of acoustics.

Inherent with the trend toward the development of larger solid propellant rocket motors (liquid as well) are the problems of analyzing the operational problem to achieve a high degree of safety.

Two major activities of the various work groups for the Armed Services Explosives Safety Board have been: the study of explosive quantity-distances, and the fragmentation hazard effects with respect to missiles and weapon systems.

An additional factor to be considered is that of noise level and the relationship of these levels to threshold limitations pertinent to personnel safety, (both operational and civilian) equipment malfunctions and structural damage including that to civilian property.

Considerable work has been done in this area and numerous reports compiled; however, in general, rocket engine noise is related to jet stream power. Acoustical power is related to an n factor (coupling coefficient) percentage of jet-stream power. Measured data indicates that acoustical power conversion factors of 0.2 to 0.8% of jet stream power are fairly representative, as governed by such factors as atmosphere, gas weight, terrain, launch pad configuration, etc. The acoustical power in watts (W) which is a measure of the converted jet-stream energy radiation is calculated by $W = \frac{1.355\ n\ M_C 2}{2}$

where:

M = Propellant flow, slugs/sec ($\mathring{w}/g$)

$\mathring{W}$ = Propellant flow, lb/sec

g = Gravity constant, 32.2 ft/sec^2

C = Effective exhaust velocity $\left[\frac{Fg}{\mathring{w}}\right]$ ft/sec

F = Measured thrust, lbf

n = Conversion factor, jet-stream power to noise

The acoustic power level in db is defined as PWL = 10 log $_{10}\frac{W}{W_o}$ where W is the acoustical power in watts and Wo is a reference re 10^{-13} watts.

Sound-pressure-level measurements in db above 0.0002 microbar are translated into power level (PWL) re 10^{-13} watts for an assumption of a spherical source by the equation:

$$\begin{aligned} PWL &= SPL + 10 \log_{10} 4 \quad r^2 \\ &= SPL + 20 \log_{10} r + 10 \log_{10} 4 \pi \\ &= SPL + 20 \log_{10} r + 11 \text{ in db re } 10^{-13} \text{ watts} \end{aligned}$$

where r is the distance from the source in feet.

The acoustical power is therefore

$$W = 10^{(0.1\ PWL\ -\ 13)}$$

Sound-pressure level = SPL is therefore calculated from the equation

$$SPL = PWL - 20 \log_{10} r - 11$$

SPL in decibels and r in distance in feet from the sound source is derived from the equation SPL = PWL - 10 $\log_{10}S$ where S is the surface area in feet through which the sound radiation takes place, which for free space = $4 \pi r^2$.

Noise is produced by the shearing action of the jet stream through the air associated basically with turbulent fluctuations in the mixing region, oscillating shock waves within the jet, and the interaction between shock waves and turbulence.

Sound Level Distance calculations as reflected by the curves shown on Slide 1 were made for a sound pressure level of 120db and for conversion factors of 0.2, 0.4, 0.6 and 0.8%. They are dependent on the characteristics of sound itself and its relationship to the frequency spectrum.

These calculations have been substantiated by data obtained from sound pressure level measurements of various large rocket test firings at Aerojet-General facility, Sacramento. Correlation has also been observed with considerable flight data as well as the Saturn test data as published by Bolt, Beraneck and Newman Inc.

Data obtained from testing of large thrust motors is indicative that the noise generated has high power, broad directivity, and a low frequency spectrum. It is not known whether the increase of low

frequency sounds is due to amplification or actual larger physical configurations, but it is certainly a function of increased acoustical power. This low frequency phenomenon is relatively new in the field and considerable more detailed and complete data from large thrust tests is required for further analysis.

To establish sound level criteria for both static tests and the launch of large booster rockets, initial ground rules have been proposed to govern siting and personnel safety. These are as follows: above 150 db no exposure; excess of 135 db ear protection required, and an evacuation perimeter of 120 db for civilian population.

Slide no. 2 shows a basic comparison between explosive quantity-distance and acoustical radius. This comparision is very conservative in that the explosive quantity-distance is plotted for 100% TNT equivalency and the acoustical distance for a 0.2% conversion factor. Were a 20% equivalency and a 0.6% conversion factor to be utilized the comparison would be more realistic and drastic. For example, for 5,000,000 lbs of propellant the explosive quantity-distance for inhabited buildings would be approximately 6,300 feet compared to 23,000 feet for 120 decibel (db).

Upon review of the latest explosive quantity-distance tables as recommended by the ASESB committee, the point at which the two distances are equal appears to be 50,000 lbs of thrust. This is for the following conditions.

1. 100% TNT equivalency.
2. 0.6% acoustical conversion factor
3. An all solid vehicle
4. Vehicle thrust to wt. ratio of 1.5
5. Mass fraction of .92

The cross over appears at approximately 2,000 ft.

Some of the acoustical problem areas which are evident and could result with the advent of larger spare vehicles are as follows:

1. Vibrational effects detrimental to the vehicle structure and electronic components.
2. Increased real estate required for siting.
3. Personnel safety and the resultant evacuation of adjacent pads during launch.
4. Structural damage to facilities.
5. Civilian nuisance factor and property damage.
6. Guidance and telemetry signal interference.

Our company has been actively engaged in studies pertinent to the acoustical field and in particular as related to large booster motors. Methods are being investigated to reduce noise and solve many of the potential problems. Initial studies and the test results have been very satisfactory and lead us to be very optimistic. It is predicted that an 8 db reduction could be realized under launch conditions. This could result in a considerable reduction in the 120 db perimeter. For example the distance for a 20-million-lb-thrust motor would be reduced from a predicted 35,000 ft to approximately 16,000 ft. or within the propellant quantity-distance requirements.

The energy levels at the long wave length, generated by lower frequencies (which appear to be predominate for large thrust motors) would be greatly attenuated with the following effects:

a. Reduction of the near field vibrational effects that are detrimental to the vehicle structure and electronic components.

b. Increases in reliability and safety factor pertinent to personnel.

c. Reduction of the noise nuisance factor affecting civilian population and the possibility of civilian property damage.

Studies are continuing and results will be published at some future date.

It is evident that a third committee will eventually be required to make a thorough study of the acoustical problems and safety criteria requirements in order to recommend industry standards for the static test and launch of rocket motors.

We all appreciate the job that the ASESB has been doing, we wouldn't be here otherwise - they're doing a fine job.

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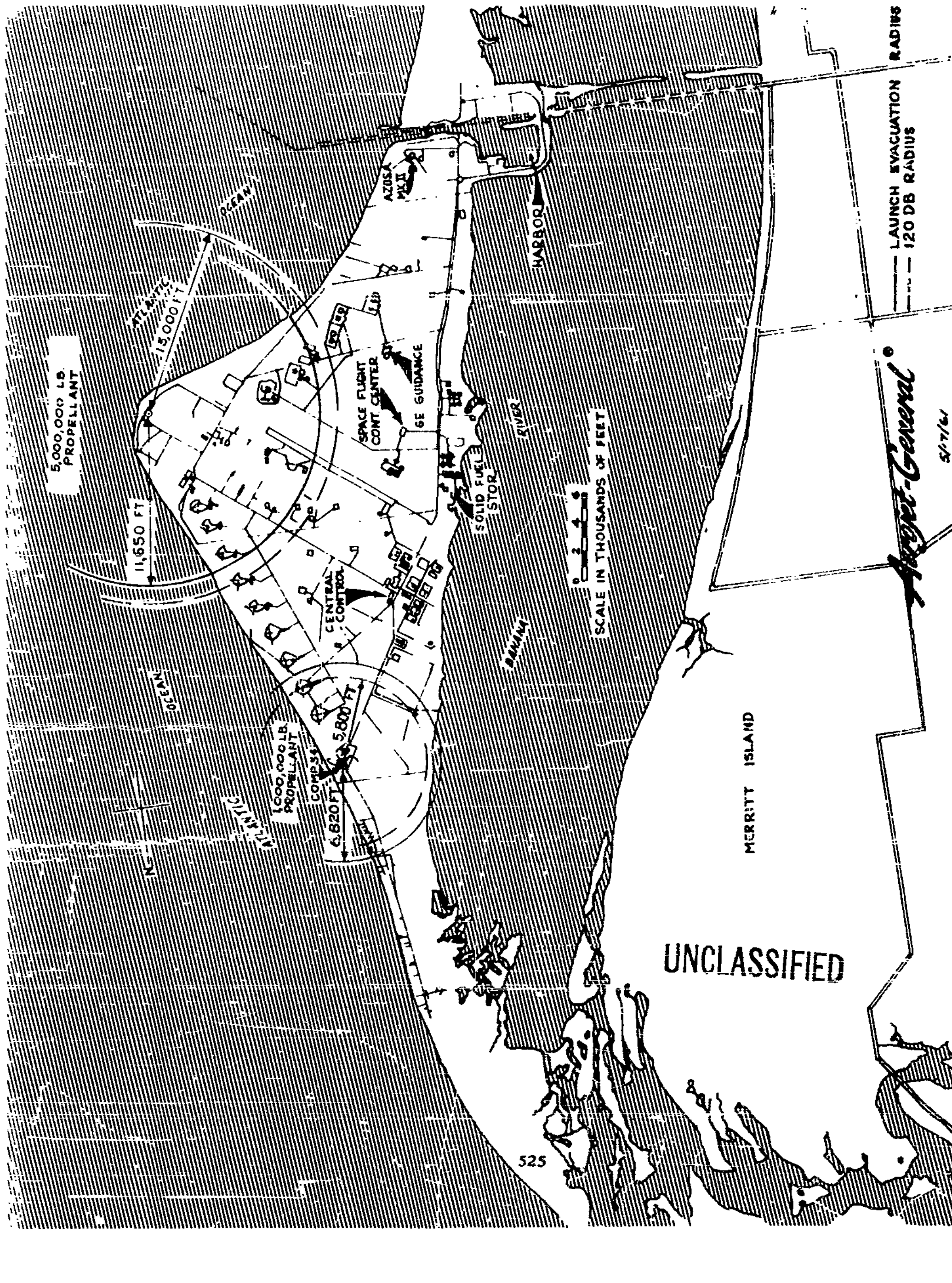

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SOUND POWER LEVEL FOR VERY LARGE SOLID ROCKET MOTORS

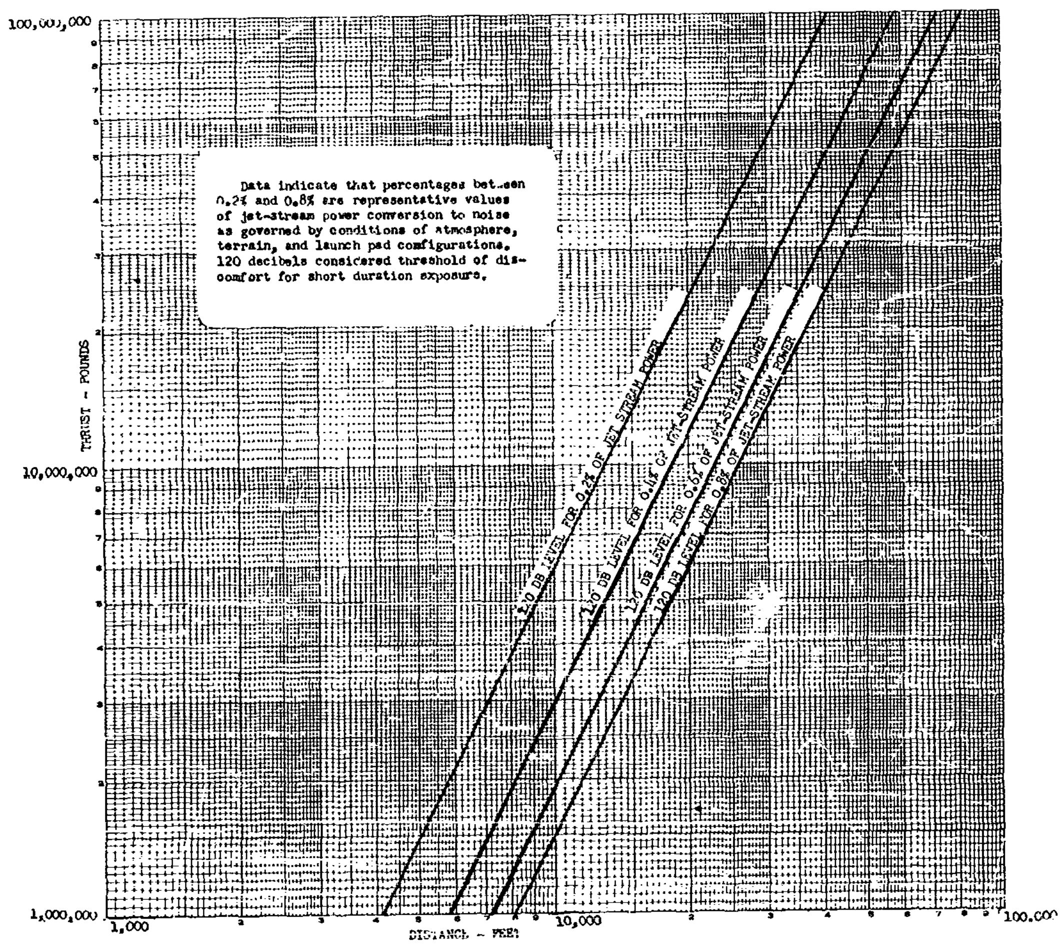

Figure 1

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Col. McCants: Thank you very much gentlemen. We are most grateful both the Members and Staff of the Armed Services Explosives Safety Board for your attendance here. We certainly hope that it's been professionally rewarding and most enjoyable. We hope that you'll return to enjoy this association in the years to come. I'm sure that some of you must have some fine suggestions for improvement - we're always striving to improve. If you would make such suggestions available to us we would appreciate your effort and assure you we will give them proper consideration. To our hosts, the NASA Langley Research Center, we would extend our warmest expression of appreciation for all of the courtesies which they've extended to us during this seminar. We are deeply indebted to Mr. Doug McCauley for making this years Seminar here at Langley possible. To all of those people unnamed who contributed to the success of this meeting allow me to express our deep thanks and appreciation.

Gentlemen, the ASESB, as always, stands ready to assist you in any way we possibly can. If we can be of assistance to you during the coming year, please do not hesitate to allow us such opportunity. We would invite you to make available to us studies and various tests which you feel are properly releasable to us. It is through such studies, etc. that we keep abreast of the progress being made. I'm sure you join

I'm sure you join with me in wishing Col. Hamilton well in his retirement from both the Army and as Chairman of the Board. I have worked almost a year with this gentleman and have enjoyed it very much. Col. Hamilton is most knowledgeable in the ways of explosives. It has been a genuine pleasure to be associated with him. I wish him well, I'm sure you do.

I am particularly interested in RF energy problems as they pertain to explosives. I would like to invite you that are also concerned with this problem to make available to us any data which you may have on the subject. We may have an opportunity at some future date of rendering some assistance in this area.

The Fourth Annual Explosives Safety Seminar is hereby adjourned, thank you again gentlemen for your participation.

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07 JUL 2000

MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

Daniel T. Tompkins

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

cc:
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DECLASSIFY ON 31 December 1973

MINUTES

of the Fourth

EXPLOSIVES SAFETY SEMINAR

on

HIGH-ENERGY SOLID PROPELLANTS

Held at the

Langley Research Center, Langley, Virginia

on

7, 8, 9 August 1962

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Armed Services Explosives Safety Board
Washington 25, D. C.

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233 attendee

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